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THE PROBLEM OF A PROPER NUTRIENT MEDIUM¹

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PART I—HISTORICAL²

Starting out to study the assimilation of various phosphates in sand cultures (1896) the senior author encountered a condition in which the nutrient solution of Hellriegel and Knop did not prove satisfactory. Occasionally some plants capable of efficient assimilation of phosphates (buckwheat, lupines) developed rather poorly on the culture solution of Hellriegel. The growth was poorer than with a nutrient solution in which a combination of phosphate and some neutral salt of potassium (KCl , K_2SO_4) was substituted for the potassium acid phosphate.

Two conditions might have been responsible for the observed phenomenon:

1. The acid reaction of the medium (pH 3.6 to 3.7) may not be tolerated equally by all plants.
2. During the growth period a neutralization of the solution and an accumulation of the titrable alkalinity take place.

The $CaNO_3$ as the chief constituent of the solution is unequally utilized; the NO_3 is assimilated faster; the excess of Ca remains behind as $Ca(HCO_3)_2$. This brings about a low assimilation of iron and phosphorus.³

The chief interest was then to see whether plants are capable of assimilating insoluble phosphates; for that reason the alkalinity of the solution of Hellriegel appeared to mark the ability of some plants to utilize the phosphorus from phosphates.⁴ This stimulated interest in finding a nutrient solution which should not tend to become alkaline but which should retain its original neutral reaction.

As NH_4Cl and $(NH_4)_2SO_4$ salts are known to be physiologically acid and therefore unsuitable as nitrogen sources for water and sand cultures it was natural to look for a different nitrogen source. In 1900, in experiments insti-

¹ Translated from the Russian manuscript by J. S. Joffe, New Jersey Agricultural Experiment Station.

² For the historical portion of the paper the senior author only is responsible.

³ For this reason an addition of acid (HCl) at some time of the experiment improves the growth of the plant in the Hellriegel solution.

⁴ In the presence of $Ca(NO_3)_2$ only a few plants like lupines, buckwheat, peas, and mustard possess this ability; the majority, however, have not shown it.

tuted to test such a nutrient⁵ the following various proportions of NO_3 and NH_4 were introduced: 1:0, $\frac{3}{4}:\frac{1}{4}$, $\frac{1}{2}:\frac{1}{2}$, $\frac{1}{4}:\frac{3}{4}$, 0:1. Two series of experiments were run: in one series the source of phosphorus was $\text{Ca}_2\text{H}_2(\text{PO}_4)_2$; in the other an excess of alkali was used to depress the possible physiological acidity of the $\text{Ca}_2\text{H}_2(\text{PO}_4)_2$.

Table 1 gives the plan and the results of the experiments.

In the series with $\text{Ca}_2\text{H}_2(\text{PO}_4)_2$, the absolute quantities of P_2O_5 (in the order of nitrogen sources as shown in table 1) in the crop were as follows: 155, 153, 254, 244, and 77 mgm.

These experiments have shown that the introduction of equal amounts of NO_3 and NH_4 [in the form of NH_4NO_3 or $(\text{NH}_4)_2\text{SO}_4$ and NaNO_3] does not create a physiologically neutral medium; but one which has a tendency to become acid. Under such conditions the phosphoric acid of the phosphates becomes available to the grain crops, which are not capable of utilizing it in the presence of nitrates.

TABLE 1
Plan and results of nitrogen nutrient tests

	SOURCE OF NITROGEN					
	NaNO_3	$\frac{1}{4}\text{NaNO}_3 + \frac{3}{4}(\text{NH}_4)_2\text{SO}_4$	$\frac{1}{2}\text{NaNO}_3 + \frac{1}{2}(\text{NH}_4)_2\text{SO}_4$	NH_4NO_3	$\frac{1}{4}\text{NaNO}_3 + \frac{3}{4}(\text{NH}_4)_2\text{SO}_4$	$(\text{NH}_4)_2\text{SO}_4$
Yield of oat tops mgm.....	6.90	22.0	20.50	18.90	19.20	1.60
P_2O_5 in crop per cent.....	0.09	0.3	0.57	0.53	0.92	1.46
Total P_2O_5 mgm.....	6.20	66.0	116.80	105.40	176.60	24.10*

* A photograph of the cultures may be found in the book of the senior author: "Düngel Lehre," Paul Parey, Berlin, 1922; also in Land. Ver. Sta. 56, 1902.

In 1901, in experiments (20) conducted with the purpose of testing various sources of nitrogen and phosphorus, the combination NH_4NO_3 and $\text{Ca}_2\text{H}_2(\text{PO}_4)_2$ proved to be the best; a litmus test of the sand of the $\text{NH}_4\text{NO}_3 - \text{Ca}_2\text{H}_2(\text{PO}_4)_2$ series after the crop was harvested showed a tendency to maintain a neutral reaction.

On the basis of the aforementioned experiments, the senior author suggested as an appropriate medium for sand cultures the use of $\text{Ca}_2\text{H}_2(\text{PO}_4)_2 - \text{NH}_4\text{NO}_3$ in place of the combination of $\text{Ca}(\text{NO}_3)_2 - \text{KH}_2\text{PO}_4$, used in the Hellriegel medium. The addition of gypsum compensated for the lack of Ca. In this medium the slight (as was then thought by the author) physiological acidity of the NH_4NO_3 produced by the formation of small amounts of HNO_3 was supposed to be balanced by the buffer action of the $\text{Ca}_2\text{H}_2(\text{PO}_4)_2$.⁶

⁵ In all cases, unless otherwise stated, sand cultures were used. The sand was washed with strong HCl.

⁶ In the beginning it was thought that the slight tendency toward acidity and decomposi-

The composition of the medium per kilogram of sand was, therefore, as follows: NH_4NO_3 —0.24 gm., $\text{Ca}_2\text{H}_2(\text{PO}_4)_2$ —0.172 gm., KCl —0.15 gm., MgSO_4 —0.6 gm., Fe_2Cl_6 —0.025 gm., $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ —0.344 gm. The medium is identical with that of Hellriegel in the amounts of the various elements except sulfur, which was in excess because of the addition of gypsum.

The new medium was known in the laboratory as the neutral medium or "Prianishnikov medium."

In later years, this medium was used very extensively parallel with the Hellriegel medium. The experiments conducted concerned the problem of the assimilation of the various sources of phosphorus and potassium in sand

TABLE 2
The yield of oats, sunflower, and buckwheat on Prianishnikov and Hellriegel media

EXPERIMENT	YIELD ON		YIELD ON PRIANISHNIKOV MEDIUM
	HELLRIEGEL MEDIUM	gm.	
On oats {	1.....	25.8	29.3
	2.....	22.3	22.6
	3.....	30.4	31.2
On sunflower.....		14.2	23.0
On buckwheat.....		23.3	17.2

TABLE 3
Analyses of plants in various media

MEDIUM	YIELD	N	K ₂ O	P ₂ O ₅	CaO	SO ₃
	gm.	mgm.	mgm.	mgm.	mgm.	mgm.
Hellriegel.....	21.46	413	644	99	212	120
Prianishnikov.....	21.73	402	715	91	113	200
Crone.....	21.33	357	510	73	235	184

cultures. The data in table 2 are just a few typical experiments conducted in 1904; they show a similarity in yield on the author's and on Hellriegel's (22) media.

tion of phosphates was due to nitrification, although the experiments were conducted in sand washed with HCl; experiments in sterilized cultures (20) repeated by Kossovitz (15) and Shulov (25) showed the same phenomenon. Later, following the author's suggestion, Shulov conducted experiments with the view of clearing up the rôle of plants in the process of decomposing the phosphates with NH_4NO_3 ; the method used was a division of the roots in various media. It was shown that the separation of the alkaline $\text{Ca}(\text{NO}_3)_2$ preventing its reacting with the phosphates does not change the relation of the grain crops to the phosphates; only the introduction of NH_4NO_3 calls forth the solubilization of phosphates under the influence of the roots of grains. Thus there was no other explanation for the observed phenomenon than to attribute it to the NH_4NO_3 producing a physiologically acid reaction. For a more detailed account the reader is referred to the Russian paper of Shulov (25), also the author's German paper (21, p. 47).

The irregularity of the results in experiments with various plants indicated the necessity of a closer study of the problem, but due to the pressure of other work it was postponed and no new experiments were conducted until the years 1911 to 1916.

In general these experiments corroborated the results for the sand cultures, but for the solution cultures the use of the new medium showed some limitations.

Just a few of the experiments with sand cultures will be reported.

In 1912 the experiments of Shulov (26) under sterile conditions showed that the young plants of corn and peas were assimilating more ammonia nitrogen than nitrate nitrogen from NH_4NO_3 ; thus it was proved that the NH_4NO_3 is a physiologically acid salt.

TABLE 4
Crop yields in various media

	PRIANISHNIKOV MEDIUM	HELLRIEGEL MEDIUM	CRONE MEDIUM	ALKALINE* MEDIUM
Alkalinity after harvesting the second crop, 0.1 N alkali.....	1.09	1.37	1.95	2.15
The yield of the third planting gm.....	19.56	16.55	14.25	12.70

* Under alkaline we understand a change of the Hellriegel medium whereby one-half of the nitrate of calcium has been replaced with nitrate of potassium. The titration was conducted with methyl orange.

TABLE 5
Effect on plants of introducing mono-calcium phosphate into Prianishnikov medium

	YIELD OF MILLET	YIELD OF FLAX	YIELD OF GARDEN CRESS
Di-calcium phosphate.....	32.9	15.0	13.9
Mono-calcium phosphate.....	5.09	4.5	Plant died

In 1914 Stolgane (30) studied the intake of nutrient substances from the media of Hellriegel, Prianishnikov, and Crone (3). The plants were analysed at four stages of their growth. The results are given in table 3.

These data show that in the first two media the conditions for the assimilation of nitrogen, phosphorus, and potassium are similar; for it was observed that the Crone medium hindered assimilation of phosphorus although without effect on the yield.

In connection with the work of Whitney and Cameron (33) in regard to the drop of yield in continuous culture, the effect of the kind of medium on the behavior of plants was studied in sand cultures. The titratable alkalinity of the media after the harvest of each crop, was determined and the yield of the continuous plantings was found to be lower as the alkalinity increased. This

alkalinity remained from the previous plantings and therefore the continuous plantings gave better yields on the medium proposed by the author than on other media; as an example we shall take the figures of the titration of an extract from a sand culture after the second crop was harvested and the yield of the third crop of lupines.⁷

As one may see from the figures, the yield of each succeeding crop is decreased as the medium becomes more alkaline on account of the growth of the plants.

In comparing the relation of the various plants and media, we did not limit ourselves to the aforementioned media in their original form. Experiments were conducted for each of 15 media in order to clear up the reasons for the success of one and the failure of the other in their applications to various plants. This brought about a rather complicated series of experiments (12).

As one would expect, two components; namely, the source of nitrogen and the source of phosphorus, are the outstanding features in a 3-salt medium. In

TABLE 6
Effect on plant growth of introducing various phosphates into the Hellriegel medium

	OATS	WHEAT	MILLET
	gm.	gm.	gm.
Primary phosphate.....	13.7	9.2	16.1
Secondary phosphate.....	6.1	4.8	....
Tertiary phosphate.....	6.7	5.4	5.8

TABLE 7
Relation of grain to straw with various media

MEDIUM	SOFT WHEAT	HARD WHEAT	BARLEY	OATS
Hellriegel.....	0.28	0.16	0.45	0.42
Prianishnikov.....	0.77	0.67	0.72	0.54
Crone.....	0.65	0.47	....	0.38

the Hellriegel medium the two components are $\text{Ca}(\text{NO}_3)_2$ and KH_2PO_4 ; in the Prianishnikov medium— NH_4NO_3 and $\text{Ca}_2\text{H}_2(\text{PO}_4)_2$; in the Crone medium— KNO_3 and $\text{Fe}_3(\text{PO}_4)_2$.⁸ If the mono-calcium phosphate instead of the di-calcium phosphate is introduced into the Prianishnikov medium the plants suffer from an acid reaction as shown in table 5.

The introduction of $\text{Ca}_3(\text{PO}_4)_2$ is favorable to growth in the presence of NH_4NO_3 . On the other hand the introduction of secondary and tertiary phosphate in place of the primary phosphate in the Hellriegel medium hampers the conditions for growth.

⁷ Each planting was allowed to develop for one month; the plants were then removed and another planting with the addition of another portion of salts was made without washing the sand.

⁸ Besides this the Crone medium contains also $\text{Ca}_3(\text{PO}_4)_2$.

The same results may be inferred from the Crone medium with its KNO_3 , $\text{Fe}_3(\text{PO}_4)_2$ constituents. Although Crone does not propose these constituents, the author's experiments with the introduction of the ammonium nitrate show that it influences unfavorably the assimilation of P_2O_5 from iron phosphate, since it creates a weakly acid reaction, whereas KNO_3 brings about a weakly alkaline reaction, and thus favors the assimilation of P_2O_5 from the iron phosphate.⁹

The solution of the problem as to which of the media is the best was complicated, since the various plants behave differently with the changes in the reaction of the medium and are different in their requirements of the nutrient substances and of their assimilation, and therefore are incomparable in the various media; and besides the order of behavior of the various plants toward this or the other medium differed with the various years.¹⁰

Without entering at this time into an analysis of the complexity of the results, a few variations noticed in the plants may be cited. These variations may be divided into the following groups:

First: For certain plants a neutral medium seems to be better than the medium of Hellriegel and Crone; this is regularly observed in cases of garden cress, in the majority of cases with flax, and occasionally for poppy seed and buckwheat.

Second: In a series of cases this medium from the standpoint of yield was very close to that of the Hellriegel medium, but either one was lower than the medium of Crone (wheat, oats, barley, corn, turnips, sugar beets, potatoes, buckwheat). The relation of grain to straw was infrequently more normal with this medium than with the other media; for instance in 1914 the differences shown in table 7 were noticed (12).

Third: The neutral medium appeared to be worse than the Hellriegel and the Crone media for peas and lupines, and partially so for sunflower; for buckwheat great variations were noticed beginning with the first and ending with the third group.

⁹ In the experiments with iron phosphate the following results (2) may be cited.

	YIELD OF BARLEY	AMOUNT OF P_2O_5 IN CROP
	gm.	mgm.
$\text{FePO}_4 + \text{NH}_4\text{NO}_3$	7.2	41.3
$\text{FePO}_4 + \text{CaCO}_3$	19.1	63.7

Introduction of CaCO_3 with $\text{Ca}_3(\text{PO}_4)_2$ brings about a depression.

¹⁰ One of the experiences with this phenomenon may be found in the following condition: If the water is introduced from the bottom, as it is in this laboratory, the soluble salts may accumulate in the surface layer, if evaporation from the surface of the vessel is increased; the insoluble portion of the medium remains uniformly distributed throughout the vessel; it is thus possible that for a short period the acid reaction caused by the one-sided utilization of the ammonium nitrate is not balanced throughout the various layers in the vessel. Although water is applied periodically to the surface of the cultures, there is still the possibility that a physiological acidity should appear more pronounced in the surface of the vessel than in the lower portion. Since the movement of the salts toward the surface depends upon the components of the sand, upon the size of particles, upon the method of watering, and upon weather conditions, it is possible that this is the cause of the irregularity that occurred during the various years.

Since in those years the method of determining the hydrogen-ion concentration was not practiced, an analysis of the results was somewhat difficult; in 1917 the war conditions caused a break in the work. Only in recent years was there a chance to return to the study of the relation of the plants and the components of the media, with the possibility of determining the changes in the hydrogen-ion concentration under the influence of the plants. This part of the work, which presented a clear picture of the relation of the plants to NH_4NO_3 , is given in the latter part of this paper.

An opinion was expressed (10) that the medium proposed by the author should be applicable also to solution cultures. However, experiments have shown that under such conditions the medium has a tendency to become more acid, as in the case of the sand cultures, and for that reason the yields at their best are

TABLE 8
Reactions of Hellriegel and Prianishnikov media with barley and buckwheat

MEDIUM†		
	BARLEY	BUCKWHEAT
Hellriegel.....	cc.* +2.5	cc. +0.5
Prianishnikov.....	-0.6	-1.2

* cc. 0.1 N alkali per 100 cc. of solution; + indicates an increase of alkalinity; - an increase of acidity; the titration was conducted with methyl orange.

TABLE 9
Behavior of barley and flax in various media studied in sand and solution cultures

MEDIUM	BARLEY		FLAX
	Sand cultures	Solution cultures	
	gm.	gm.	gm.
Hellriegel.....	11.7	11.3	12.8
Prianishnikov.....	11.3	2.6	4.5
Crone.....	11.4	12.4	12.5

only equal to those which are obtained with the Hellriegel medium—at times even worse. The author was forced to the conclusion that in its original composition the medium proposed for sand cultures may not be recommended for solution cultures. That the movement toward acidity is responsible for this may be proved by the fact that a replacement of the di-calcium phosphate with the mono-calcium phosphate has a still worse influence on the plants; and besides an analysis of the solution after the experiment, showed a noticeable titratable acidity in those cases where the plants showed injury. Thus in the experiments of Arnold (1), the shifting of the reaction as compared with the original was measured as indicated in table 8.

It is interesting to note that in this experiment the buckwheat on the Prianishnikov medium shows symptoms of injury. The yields in this experiment did not vary sharply (11.4 and 11.1 gm. for the barley; 7.75 and 6.25 gm. for buckwheat); in the experiments of 1913 conducted by Stolzane (30) the results for the water cultures were unfavorable, also from the standpoint of yield.

As far as the differences in behavior of the media studied in sand and in solution cultures are concerned the following may be suggested:

First: The distance separating the precipitated phosphate in the ammonium nitrate cultures has its influence; it is possible that at a slow rate of diffusion the root hairs may accumulate around themselves an injurious degree of acidity, which in this case was eliminated only once in 24 hours by stirring.¹¹ Later experiments have shown that mature plants are capable of changing the reaction within 2 hours, and that the reactions of ammonium nitrate solutions approach those of ammonium chloride solutions.

Second: The question was raised whether in the case of the sand cultures adsorption influences in one way or another the composition of the medium, making it more favorable

TABLE 10
*Results of experiments conducted during 1916**

MEDIUM†	YIELD OF BARLEY		YIELD OF OATS		YIELD OF RYE	
	Without charcoal	With charcoal	Without charcoal	With charcoal	Without charcoal	With charcoal
	gm.	gm.	gm.	gm.	gm.	gm.
Hellriegel.....	17.1	....	16.4	31.8	....	....
Prianishnikov.....	22.0	32.7	....	....	13.0	18.8
Acid.....	16.6	33.5	6.5	25.7	14.4	59.0
Alkaline.....	16.5	29.5	12.2	25.9	8.3	17.5

* Jakushkin, I. V. On the influence of finely ground charcoal on the yield with different nutrient media in sand cultures. (Experiments conducted in the laboratory of Prianishnikov in 1916. Not published.)

† Under the acid medium we understand the Hellriegel medium replacing $\text{Ca}(\text{NO}_3)_2$ with NH_4NO_3 , and alkaline medium—the medium of Hellriegel replacing a half of the $\text{Ca}(\text{NO}_3)_2$ with KNO_3 .

for the plants, or whether it influences the shifting of the reaction from the neutral point. The latter assumption was confirmed by the fact that finely granulated charcoal introduced into the medium obliterated the shifting of the reaction.

Thus charcoal is capable of eliminating the injurious influence of the reaction's shifting either towards acidity or alkalinity: this is in accordance with the data concerning the ability of charcoal to absorb energetically the H and OH ions as pointed out by Michaelis (16). For the sand, however, no such

¹¹ That the formation of a precipitate on the bottom of a vessel may be a factor in hindering the development of the plants may be deduced from the experiments conducted in the laboratory by M. I. Sidorin (27, 28); it was shown that the plants may suffer from chlorosis even though iron phosphate is present at the bottom of the vessel; whenever the distance between the roots and the bottom of the vessel was appreciable and the stirring was not done frequently enough.

phenomenon could be observed, although it is known that the absorption phenomenon in general is demonstrable in the sand culture results.¹²

Coming back after a time to the study of the individual components of the author's medium and utilizing the methods of determining the hydrogen-ion concentration, the authors have shown that the physiological acidity of NH_4NO_3 was more pronounced than it was ever supposed; it seems that the plant is capable of making this medium in certain movements just as acid as with ammonium chloride.

The experiments of Domontovitch described later have shown that the more developed plants, after 2 hours contact in a solution of ammonium nitrate and ammonium chloride, are capable of changing appreciably the pH of the solution; the experiments of Kupreyenok¹³ conducted in 1922 show that in a vessel of small volume, plants are capable of changing the reaction of the medium from pH 6.2 to 3.9 within 24 hours. (This experiment was conducted under conditions of changing the solutions and it was apparent that with ammonium salts a change of the medium every other day does not prevent a shifting of the reaction).¹⁴

This explains the fact that in culture solutions stirred once in 24 hours, the presence of ammonium nitrate in solution and of di-calcium phosphate as a precipitate does not eliminate the unequal accumulation of acid; the latter may therefore become concentrated around the roots in undesirable quantities.

In an effort to determine which one of the unknown causes plays a more important rôle in the irregularities noticed between solution cultures and sand cultures, the improvement of the author's medium for solution cultures may be sought in two directions:

First: With the same source of P_2O_5 — $\text{Ca}_2\text{H}_2(\text{PO}_4)_2$ —to increase the ratio of NO_3 to NH_4NO

¹² To check the assumption on the rôle of absorption in regulating the reaction O. V Sarobina conducted the following experiments: Sand washed with strong HCl was moistened with a solution of one of the nutrient media (Hellriegel, Prianishnikov, Crone) and upon the expiration of one hour, a replacement of the solution by means of alcohol following the method of Isterekov (9) was carried out. The replaced solution was analyzed for all the cations and anions introduced and was compared with the original composition. However, the experiments were not successful in establishing any relation of the sand to the component parts of the medium, which contains ammonium nitrate as compared with other media. In checking up the second variable on the rôle of absorption, it was apparent that the sand used was capable of weakening somewhat the acid reaction of the solution in contact with it; for instance, the medium having an initial pH of 3.92 gave a pH of 4.76 after coming in contact with the sand; the solution, which was alkaline, did not change upon contact with the sand. This phenomenon may be explained not only by adsorption but by the impurities found in the sand which are capable of neutralizing acid solutions.

¹³ Kupreyenok. On the speed of reaction changes in solution by plants with various sources of nitrogen. (Investigation conducted in the laboratory of Prianishnikov during 1922. Not published.)

¹⁴ That the change of the solutions does not prevent the appearance of injurious influences on the part of the physiologically acid salts was observed in 1908 but there were no determinations of pH made then.

($\frac{1}{2}$ or $\frac{1}{3}$). This change is corroborated by the work of various American workers, such as Wolkoff (34).

Second: By increasing the amount of base which is carried with the phosphates; that is, to try the influence of $\text{Ca}_3(\text{PO}_4)_2$ in place of $\text{Ca}_2\text{H}_2(\text{PO}_4)_2$. Incidentally, in sand cultures it has been repeatedly noticed that an improvement of growth is marked by replacing the di-calcium phosphate with freshly precipitated tri-calcium whenever the source of nitrogen was NH_4NO_3 . However, more experiments in this direction are desirable.

As was shown in the experiments of 1911 to 1916, among other media, various modifications of the Crone media were used; by itself this medium appears to be universal, giving in most cases very good results (except with garden cress and partially with flax), also giving regular yields of rye in both sand and water culture; still this medium may be improved. Thus, by making several changes in this medium it was observed that by replacing the $\text{Fe}_3(\text{PO}_4)_2$ with $\text{Fe}_2(\text{SO}_4)_3$, and increasing the portion of $\text{Ca}_2(\text{PO}_4)_2$ to keep up the P_2O_5 content,

TABLE 11
Results with corn plants grown for 10 days in various media (24)

EXPERIMENT	AMMONIUM NITRATE		AMMONIUM CHLORIDE	
	Before experiment	After experiment	Before experiment	After experiment
1	pH 7.0	pH 3.7	pH 6.9	pH 3.7
2	pH 7.0	pH 3.9	pH 6.9	pH 4.0
3	pH 6.8	pH 4.2	...	...
4	pH 6.8	pH 4.1	...	...

TABLE 12
Results of Jakushkin's experiments on modified Crone medium

MEDIUM	MILLET	BUCKWHEAT	LUPINES
Original Crone.....	33.3	11.8	21.7
Modified Crone.....	48.2	17.8	26.5

the yield was increased. Table 12 taken from the experiments of Jakushkin (12) gives the results on the modified Crone medium.

The modified Crone medium¹⁵ infrequently gave better results than any other media. When these experiments were conducted, the present day methods of determining the reaction had not been introduced, but there is reason to suppose that the same medium is capable of keeping the reaction within limits. Besides the forms of the compounds, this medium differs from Knop's and

¹⁵ The modification makes the medium a non-Crone medium, since the characteristic of the Crone medium is the presence of iron phosphate. The modification is similar to the Sax medium, except that the former contains less salts of iron and the latter contains NaCl.

Hellriegel's media by a larger amount of soluble salts; this concentration of salts is tolerated because they are neutral salts. It is worth mention that a certain increase in the osmotic pressure through salts ineffective from the standpoint of nutrition may also be useful, as shown by Malioushitsky and Tulaikov (32). In the author's cultures there was not only an increased assimilation of nitrogen under the influence of NaCl (29) but also a greater accumulation of oil in the seeds of flax and of mustard, an increase in the percentage composition of sugar in tomatoes, and also an increase in the soluble carbohydrates in the vegetative portion of the grain crops.¹⁶

It is thus possible that in the Crone medium besides the forms of the nutrient salts, the increased concentration of the nutrient solution, which was made possible by the exclusion of the acid phosphate, also has an influence.

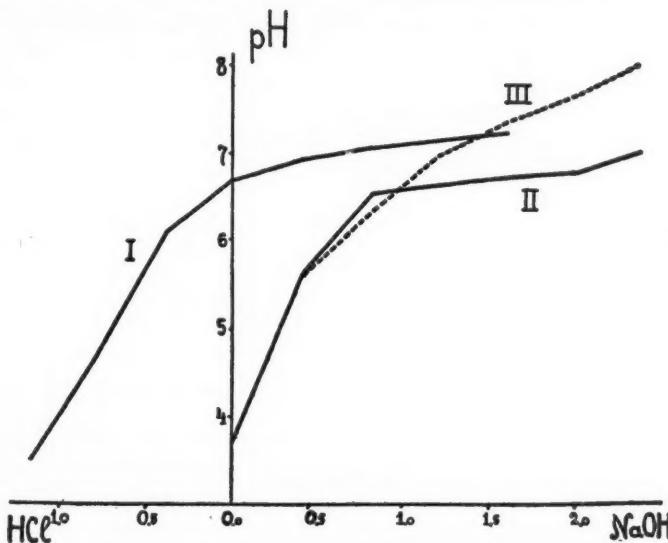


FIG. 1. GRAPHS SHOWING THE TITRATION OF THE PRIAMSHNIKOV AND HELLRIEGEL MEDIA AT START (I), AFTER 24 HOURS (II), AND AFTER $\frac{1}{2}$ HOUR (III)

PART II¹⁷

The experiments described below are a continuation of the investigations of Prianishnikov reported in the first part of this paper.

Special emphasis has been laid on the factors influencing the reaction of

¹⁶ Pereturin. On the influence of osmotic pressure of the solutions on the composition of plants. (Investigation conducted in the laboratory of Prianishnikov in 1922. Not published.)

¹⁷ The text of this second part has been prepared by M. K. Domontovitch.

nutrient medium during the growth period of plants. The factors of the dynamics of the reaction of nutrient media investigated were as follows:

1. Physiological acidity or alkalinity of the nitrogen sources, NH_4 or NO_3 .
2. The buffer action of the media.
3. Specificity of plant species.

The course of the reaction in solution cultures was the subject of investigation by Duggar (4), Jones and Shive (14), Hoagland (8), Theron (31), and others. Recommendations of a special nitrate ammonia medium are given in the work of Wolkoff (34) and Hartwell and Pember (5). The latter attempted to control the reaction by the combination of $\text{NH}_4 + \text{NO}_3$; thus the recommendation of Hartwell and Pember coincides with that of Prianishnikov. The difference consists in that in the Prianishnikov medium the buffer action of di-calcium phosphate is utilized along with the physiologically acid ammonia nitrate. A series of interesting observations on the question of the physiological acidity of ammonium salts was made by Olsen (17), Jacobs (11), Hoagland and Davis (8), and Jones and Shive (14). During the progress of the work the aforementioned investigations were not available to the author and could not be utilized. Besides, their work dealt chiefly with solution renewal whereas the work of the author deals chiefly with constant media.

Buffer action of the Hellriegel and Prianishnikov media

The original reaction of these media is controlled chiefly by the phosphates, KH_2PO_4 or $\text{Ca}_2\text{H}_2(\text{PO}_4)_2$, and by FeCl_3 . The changes in reaction of these media upon the addition of NaOH or HCl are shown in figure 1. The method used in obtaining these curves was as follows:

Into a series of flasks, 100 cc. of the respective media was poured and additions of 0.1 *N* NaOH or HCl were made. The pH determinations were made with the Quinhydrone electrode after 24 hours and for the Hellriegel medium also after 30 minutes (dotted line of the curve).

A comparison of the pH value of the Hellriegel medium after 30 minutes and after 24 hours shows that the pH of this medium does not attain its equilibrium at once; it depends on the precipitation of the phosphates of calcium. On account of the large amount of FeCl_3 (about one-half to a milliequivalent per liter) the original reaction of the Hellriegel medium is strongly acid (pH 3.6 to 3.7). In solution cultures such a reaction may exert an injurious influence on the roots of young plants of several species. In sand cultures where the sand is practically never absolutely pure, but contains some neutralizing properties, the critical acidity produced by a large amount of FeCl_3 does not show itself. According to some calculations, a titration with phenolphthalein should give an acidity equivalent to 2.5 cc. of 0.1 *N* NaOH for every 100 cc. of the Hellriegel medium (since the medium contains a millimol of KH_2PO_4 with an excess of calcium and approximately half a milliequivalent of FeCl_3). This titration does not take into consideration the acidity produced by the

CO_2 . The amount of alkali necessary to bring about a pH of 7.0 in the Hellriegel medium is not regular, but depends upon the time the reading is taken.

The original reaction of the Prianishnikov medium is close to that of the neutral point; namely, pH 6.6 to 6.7. In order to acidify it and to bring it to a pH 4.0, 0.9 to 1.0 cc. of 0.1 *N* HCl is necessary. Thus, as the Prianishnikov medium shows a clear buffer action against acidifying, one may find a justification for the combination of the physiologically acid ammonium nitrate with di-calcium phosphate; the latter is capable of absorbing the H ions and of

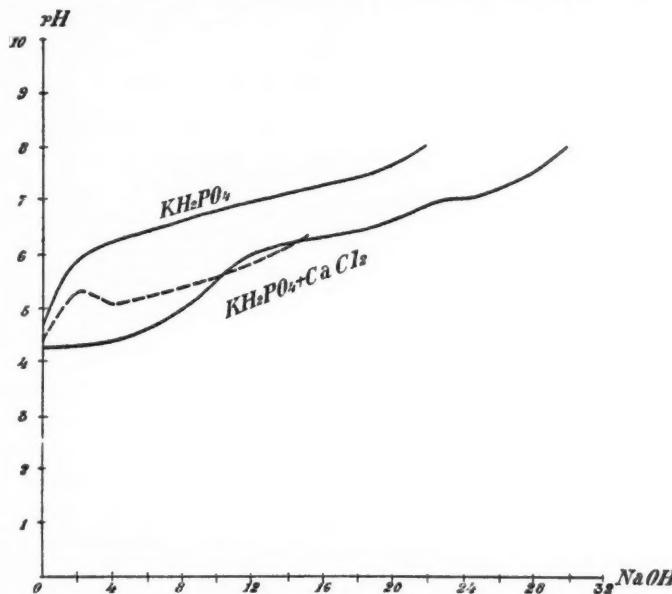


FIG. 2. GRAPHS SHOWING THE TITRATION OF 0.05 *M* SOLUTION OF KH_2PO_4 AND 0.05 *M* $\text{KH}_2\text{PO}_4 + 0.02 \text{ M} \text{CaCl}_2$

changing into the mono-phosphate. However, this buffering property of the Prianishnikov medium is not sufficient in some cases. It would be interesting to increase the buffer properties of this medium by increasing the amount of di-calcium phosphate or by replacing the FeCl_3 with iron tartarate or something similar.

In order to illustrate the influence of the precipitation of phosphates of calcium on the titration curve, figure 2 is given, in which the titration graphs of 0.05 *M* solution of KH_2PO_4 and 0.05 *M* $\text{KH}_2\text{PO}_4 + 0.02 \text{ M} \text{CaCl}_2$ are given. The pH determinations were made after additions of increasing amounts of a solution of 0.08 *N* NaOH; the readings were taken after 3 hours and after 20 days. In the medium without the calcium the reaction has not changed; in the medium with calcium the reaction after 3 hours is represented by a dotted line, and the reaction after 20 days by a solid line.

If a study is made of this solid line, which corresponds to a condition of equilibrium between the solid and the liquid phase, one may note that the addition of calcium salt to a solution of KH_2PO_4 brings forth two points of buffer activity: 1. Approximately between pH 3.3 and 3.7. 2. Between pH 6.0 and 6.4. An analysis of the first point corresponds to the precipitation of di-calcium phosphate (this may be called the phenomenon of buffer effect of precipitation). The second point of the buffer action corresponds to the inversion of di-calcium phosphate into tri-calcium phosphate (we thus have the buffer effect of the conversion into the solid phase).

TABLE 13
Influence of sprouted corn plants on the solutions of ammonia salts

COMPOSITION OF MEDIUM	REACTION OF ORIGINAL SOLUTION		REACTION AT END OF EXPERIMENT	
	pH	pH	pH	pH
NH_4NO_3	7.0		3.7	
NH_4Cl	6.9		3.7	
$\text{NH}_4\text{NO}_3 + \text{HCl}$	4.4		3.8	
$\text{H}_2\text{O} + \text{HCl}$	4.4		5.5	

TABLE 14
Oat plants grown under daylight conditions

COMPOSITION OF MEDIUM	REACTION OF MEDIUM					
	Before experiment		After 1 hour		After 24 hours	
	a	b	a	b	a	b
$0.001 \text{ N } \text{NH}_4\text{Cl} + \text{HCl}$	pH 4.2	pH 4.2	pH 4.4	pH 4.3	pH 3.8	pH 3.8
$0.001 \text{ N } \text{KCl} + \text{HCl}$	4.2	4.2	4.4	4.2	4.9	5.0
$0.001 \text{ N } \text{MgCl}_2 + \text{HCl}$	4.2	4.2	5.0	4.9	5.6	5.6
$0.001 \text{ N } \text{CaCl}_2 + \text{HCl}$	4.2	4.2	4.3	4.5	5.6	5.6

The influence of plants on the solutions of ammonia salts

When it was found that the NH_4NO_3 behaves as a physiologically acid salt, the question came up as to how this property may be changed under the influence of the reaction of the medium. The influence of weak concentrations of HCl on the utilization of ammonium nitrate by plants was therefore tried. Table 13 shows how sprouted corn plants in the experiments of Prianishnikov have shifted the reaction in a solution of ammonia salts during the period of 10 days.

Thus after 10 days of contact with the plants the medium shifted toward the acid side even in the solutions to which an acid was added. Thus the pre-

TABLE 15

The changes in reaction of solutions of NH_4Cl and NH_4NO_3 under the influence of the roots of peas and oats and the absorption of nitrogen from these solutions

EXPERIMENT NUM- BER	KIND OF PLANT AND AGE	TIME OF CONTACT OF PLANTS IN SOLU- TION CULTURE	COMPOSITION OF MEDIA	BEFORE THE EXPERI- MENT		AFTER THE EXPERI- MENT		NITROGEN ABSORBED	
				hrs.	pH	pH	per cent	per cent	
1	Oats, 22 days	2	0.001 N NH_4NO_3		5.8	4.8	5.0	27.9	
			0.001 N $\text{NH}_4\text{NO}_3 + \text{HCl}$		3.7	3.8	38.7	11.5	
			0.001 N NH_4Cl		5.9	4.6	...	29.5	
			0.001 N $\text{NH}_4\text{Cl} + \text{HCl}$		3.6	3.7	...	18.8	
2	Oats, 13 days	2	0.0005 N NH_4NO_3		5.4	5.4	0	51.6	
			0.0005 N $\text{NH}_4\text{NO}_3 + \text{HCl}$		3.7	4.2	11.5	40.4	
			0.0005 N NH_4Cl		5.4	5.3	...	50.2	
			0.0005 N $\text{NH}_4\text{Cl} + \text{HCl}$		3.7	3.7	...	38.4	
3	Oats, 13 days	2	0.0005 N NH_4NO_3		5.4	5.4	18.3	51.5	
			0.0005 N $\text{NH}_4\text{NO}_3 + \text{HCl}$		3.7	4.2	37.9	44.6	
			0.0005 N NH_4Cl		5.4	5.3	...	50.7	
			0.0005 N $\text{NH}_4\text{Cl} + \text{HCl}$		3.7	4.2	...	52.5	
4	Oats, 60 days	3	0.001 N NH_4NO_3		6.1	5.7	34.4	30.0	
	Oats, 30 days		0.001 N NH_4NO_3		6.1	6.1	0	31.5	
	Oats, 14 days		0.001 N NH_4NO_3		6.1	5.4	25.0	27.1	
5	Oats, 74 days	2	0.001 N NH_4NO_3		6.4	6.2	17.2	14.7	
	Oats, 44 days		0.001 N NH_4NO_3		6.4	6.6	28.5	32.3	
	Oats, 28 days		0.001 N NH_4NO_3		6.4	6.3	0	22.6	
	Oats, 14 days		0.001 N NH_4NO_3		6.4	6.2	0	18.3	
6	Peas, 20 days	2	0.0003 N NH_4NO_3		5.4	4.8	0	7.7	
			0.0003 N $\text{NH}_4\text{NO}_3 + \text{HCl}$		4.0	4.1	0	0	
			0.0003 N NH_4Cl		5.3	4.4	...	11.0	
			0.0003 N $\text{NH}_4\text{Cl} + \text{HCl}$		4.0	4.0	...	0	
7	Peas, 20 days	4	0.0003 N NH_4NO_3		5.4	4.8	0	33.7	
			0.0003 N $\text{NH}_4\text{NO}_3 + \text{HCl}$		4.0	6.2	33.6	0	
8	Peas, 30 days	3	0.0001 N NH_4NO_3		6.4	5.5	19.3	61.5	
			0.0001 N $\text{NH}_4\text{NO}_3 + \text{HCl}$		5.0	5.3	18.1	54.0	
			0.0004 N NH_4NO_3		6.2	5.3	0	23.1	
			0.0004 N $\text{NH}_4\text{NO}_3 + \text{HCl}$		4.9	5.2	0	25.2	
9	Peas, 14 days	2	0.0002 N NH_4NO_3		6.4	6.2	0	26.1	
			0.0002 N $\text{NH}_4\text{NO}_3 + \text{HCl}$		3.9	5.8	3.7	0	

ponderance of assimilation of ammonia over that of nitrate nitrogen is not dependent on the reaction of the medium.

The foregoing experiment was conducted in the dark. In another experiment conducted under daylight conditions with oat plants which were 25 cm. in length, the results shown in table 14 were obtained.

In this experiment during the first hour there was a tendency to neutralize somewhat the acid solution. After 24 hours, on the other hand, there was a noticeable tendency toward acidifying the solution containing the ammonia salts.

A series of experiments with solutions of NH_4Cl and NH_4NO_3 , in which the absorption of NH_4NO_3 and the changes in reaction were determined, was conducted by Domontovitch and Drachev. After the roots have been washed with distilled water the experimental plants grown in complete nutrient solutions were put into the experimental media for a period of 2 to 4 hours. The results are given in table 15.

The data given show that within 2 to 4 hours there was a shift in the reaction toward an increase of acidity in the unacidified solutions of NH_4Cl and NH_4NO_3 ; in the acidified solutions there was a slight decrease of acidity (0.1 to 0.3 pH). There was a decrease in acidity in the same ratio on both of the media $\text{NH}_4\text{Cl} + \text{HCl}$ and $\text{NH}_4\text{NO}_3 + \text{HCl}$. From equivalent solutions of $\text{NH}_4\text{NO}_3 + \text{NH}_4\text{Cl}$ the ammonia was absorbed with the same intensity. In the majority of cases the NH_4 was absorbed faster than the NO_3 in the unacidified NH_4NO_3 solutions. When the NH_4NO_3 solutions were acidified the amount of absorbed nitrate nitrogen increased and the amount of absorbed ammonia nitrogen decreased; however, even on the acidified solutions occasionally the ammonia nitrogen was absorbed more energetically than the nitrate nitrogen.

In general one might say that the physiological acidity in these experiments shows itself clearly on the unacidified solutions; two indications characterize it: 1. The excessive absorption of cations over anions, 2, the shift of the reaction toward an increase of the pH reading of the acidified solutions. On the solutions of $\text{NH}_4\text{NO}_3 + \text{HCl}$ the first indication of physiological acidity infrequently continued to appear although the other at times was obliterated. We may assume (on the strength of the experiments cited above) that with a prolongation of the time of the experiments, there would have been a reverse movement of the reaction toward an increase of acidity, even on the solutions with NH_4NO_3 which were slightly acidified.

The change in reaction of the solution cultures under the influence of the growth of plants in NH_4NO_3 and nutrient media

In nutrient solution cultures with corn various amounts of NaNO_3 and NH_4Cl were used. The solutions were not renewed. The changes in reaction are given in table 16. This table shows that the tendency toward acidity becomes noticeable when ammonia nitrogen is substituted for one-fourth of the nitrate nitrogen; under the conditions of the experiment, this combination

appeared to be the optimum, since at a wider ratio the plants suffered from an excess of acidity and on the purely nitrate media the corn plants became strongly chlorotic.

In the experiments in 1924 a comparison was made of the effect of various types of plants on the reaction of the nutrient media, various sources of nitrogen being used in nutrient cultures. The composition of each liter of this solution for both media as well as the nitrogen source was as follows: KCl—0.03 gm.,

TABLE 16

The influence of the ratio $\text{NO}_3:\text{NH}_4$ on the change of reaction in solution cultures with corn

$\text{NO}_3:\text{NH}_4$ IN EQUIVA- LENTS	TIME PERIOD IN DAYS									
	Start		7		10		14		20	
	pH	pH	pH	pH	pH	pH	pH	pH	pH	
1:0	4.7	5.4	5.6	5.7	5.9	6.0	5.9	6.0	6.3	
$\frac{3}{4}:\frac{1}{4}$	4.7	4.5	4.3	4.2	3.9	4.1	4.5	4.7	4.0	
$\frac{1}{2}:\frac{1}{2}$	4.7	4.5	4.3	4.1	3.8	3.5	3.4	3.5	3.4	
$\frac{1}{4}:\frac{3}{4}$	4.7	4.5	4.3	4.1	3.7	3.4	3.4	3.0	3.0	
0:1	4.7	4.3	3.9	3.6	3.4	3.2	3.0	2.8	2.8	

TABLE 17

The change of reaction during the growth period of the plants in solution cultures on a complete medium containing various sources of nitrogen

NUMBER OF DAYS	NaNO ₃					NH ₄ NO ₃					NH ₄ Cl						
	Oats	Corn	Peas	Clover	Buckwheat	Oats	Corn	Peas	Clover	Beans	Buckwheat	Oats	Corn	Peas	Clover	Beans	Buckwheat
	pH	pH	pH	pH	pH	pH	pH	pH	pH	pH	pH	pH	pH	pH	pH	pH	
0	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	
5	...	6.3	...	5.5	5.5	...	4.2	...	5.2	5.5	...	3.6	...	5.1	4.1	...	
8	6.1	6.3	5.7	...	...	5.3	3.8	4.5	...	...	...	4.5	3.1	4.4	...	...
11	6.5	...	6.5	...	...	5.6	4.9	...	4.3	...	...	5.0	3.7	...	3.9	...	4.5
16	7.3	6.8	7.2	6.5	6.2	5.6	4.0	3.3	4.5	4.0	4.2	4.3	3.3	2.9	4.0	3.7	3.7
20	7.4	...	7.2	6.6	6.3	5.7	3.9	...	4.2	4.0	3.9	4.0	3.3	...	3.9	3.7	3.6
28	...	6.9	...	7.0	6.9	5.8	...	3.4	...	3.9	3.6	3.6	...	2.9	...	3.7	3.6

KH_2PO_4 —0.06 gm., MgSO_4 —0.06 gm., CaCl_2 —0.08 gm., CaSO_4 —0.12 gm., Fe—0.05 mgm. (tartarate). As for the nitrogen source in medium 1 there was NaNO_3 —0.26 gm.; in medium 2, NH_4NO_3 —0.12 gm.; in medium 3, NH_4Cl —0.16 gm.

Three plants were put into each vessel of 1.8 liter capacity. The contents of the vessels were stirred every half hour. The results of the experiment are given in table 17.

From the observations on the growth of the plants, the following was noted:

On the NH_4Cl medium the grain crops and legumes were killed. The leaves dried up or dropped off. The killing of legumes (peas, clover, beans) took place at pH 3.9 to 3.6; oats died at pH 3.3; and corn at pH 3.1 to 2.9; the buckwheat was an exception. This survived, and at the end of the experiment the reaction of the medium was 3.5. Although the plants were stunted they remained alive and to all appearances seemed to be healthy. On the NH_4NO_3 medium the beans and clover seem to have suffered most; the peas looked better; the other plants maintained their normal appearance; on the corn, notwithstanding the 13 days of contact with the solution of pH 3.3 to 3.4, only the tips of the roots appeared to die off. On the NaNO_3 medium the plants were healthy except for the beans and clover, which wilted toward the end of the experiment. If attention is directed to the general character of the change in reaction of the solution and especially to the direction of the change, the conclusion may be drawn that in the experiments described, all types of plants in general have shown analogous influence on the reaction. There were no sharply defined qualitative differences among the plants used in the experiment.

On the NH_4Cl media the plants lowered the pH of the solution somewhat faster, bringing about the point of toxic limit after 15 or 20 days. On the NH_4NO_3 media there was a slow and gradual approach to this limit accom-

TABLE 18
The change of reaction during the growth period of wheat and buckwheat grown on nitrate media

PLANTS	SOURCE OF P_2O_5	BEGINNING	AFTER 20 DAYS	AFTER 30 DAYS
		pH	pH	pH
Wheat.....	KH_2PO_4	4.1	6.4	...
Buckwheat.....	KH_2PO_4	4.1	5.6	5.8
Buckwheat.....	Saratov phosphate	5.5	5.9	6.0
Buckwheat.....	Without phosphate	4.1	4.1	4.4

panied by a greater or less depression of growth. In the nitrate media the reaction approached the narrow interval of reaction around the neutral point.

There were quantitative differences in the speed of change of reaction among the individual plants; these differences are not accidental in the experiment; they are characteristic for the particular species.

The higher limit of reaction for oats and corn on the media with ammonium chloride as compared with the legumes may be ascribed to the sensitiveness of the legumes to an acid reaction. The absence of killing effects on buckwheat in the NH_4Cl medium may be explained by the ability of this plant to withstand a wide range of reaction after which a depression of the growth takes place; only after this limit is a killing reaction possible for buckwheat. If the variations in pH for the ammonium nitrate and the ammonium chloride media are noted, after the twentieth day the following is apparent: For oats, pH 0.6; corn—0.4; buckwheat—0.4; peas—0.3; clover—0.3; beans—0.3. The figures for the various plants (except oats) are very similar. On the neu-

tral medium one property is outstanding; namely, the appreciable constancy of the reaction in the vessels with buckwheat. The tendency to approach the neutral point was apparent up to end of the experiment. In another experiment where only nitrate media were used the results shown in table 18 were obtained.

In this case, therefore, the weakly acid reaction of the nitrate medium became more constant under buckwheat than under wheat (notwithstanding the weak development of the wheat). On the phosphates (Saratov) the development of buckwheat was just as successful as on the KH_2PO_4 ; therefore the (Saratov) phosphate was assimilated by the buckwheat at a reaction of the medium ranging between pH 5.5 and 6.0.

SUMMARY

Part I

The NH_4NO_3 nutrient medium proposed by Prianishnikov on the basis of his experiments with sand cultures during 1900-1901 gave results close to those obtained with the Hellriegel medium; with certain plants (like water cress and flax) the medium gave even better results, but with others (like lupines and peas) it gave poorer results than with the Hellriegel medium.

The cause of these differences may be looked for in the following conditions:

The earlier assumption that the reaction of this medium, which is close to neutrality will not shift either way on account of the buffer action of the di-calcium phosphate, did not materialize. Further experiments have shown that the physiological acidity of ammonium nitrate is a great deal stronger than was thought in the beginning; the acidity may approach a point comparable to that produced by the presence of ammonium chloride. Thus although in the Hellriegel medium there is a shift of the reaction from acidity to neutrality, in the Prianishnikov the reverse is true. Since various plants on one hand tolerate differently shifting of the reaction and on the other hand have a different power of producing changes in reaction, the results of applying one or the other media are subject to change under the influence of the type of plant.

Besides, it was observed that the Prianishnikov medium infrequently gave poorer results in nutrient solution cultures than in sand cultures. The causes of differences between the nutrient solution cultures and the sand cultures may be ascribed to the possible buffer action of the impurities found in sand; it may also be caused by the unequal distribution of the NH_4NO_3 and $\text{Ca}_2\text{H}_2(\text{PO}_4)_2$ in the vertical column of the nutrient cultures as compared with the sand cultures. For this reason the physiological acidity of the ammonium nitrate is not neutralized by the action of the di-calcium phosphate, which is found as a precipitate on the bottom of the vessel. The stirring of the solution at 24-hour intervals is not sufficient to prevent the acidity produced around the roots from doing the damage. In view of the above, the solution cultures for the best results ought to have such a modification of the nutrients that the ratio of nitrate nitrogen to ammonia nitrogen would be more than unity.

Among other media which were studied, the one of Crone with slight modifications was successful; the changes produced consist in replacing the $\text{Fe}_3(\text{PO}_4)_2$ with $\text{Fe}_2(\text{SO}_4)_3$ with a corresponding increase in the amount of $\text{Ca}_3(\text{PO}_4)_2$.

Part II

The experimental part of this paper deals with a detailed study of the mutual influence of the different ingredients of the Prianishnikov medium; the primary thought was to reduce the physiological acidity of NH_4NO_3 by the buffer activity of $\text{Ca}_2\text{H}_2(\text{PO}_4)_2$.

The titration curves of the Hellriegel and Prianishnikov media show the greatest buffer activity at a pH close to neutrality. The buffer action depends not only on the conversion of the phosphates, $\text{HPO}_4^{''} + \text{H}' \rightleftharpoons \text{H}_2\text{PO}_4'$ in the solution, but also on the precipitation or solubility of the calcium phosphate.

To illustrate the buffer effect of precipitation of phosphates of calcium and the buffer effect of the conversion of the solid phase $(2\text{CaHPO}_4 + \text{Ca} \rightleftharpoons \text{Ca}_3(\text{PO}_4)_2 + 2\text{H})$, the titration curves of KH_2PO_4 and $\text{KH}_2\text{PO}_4 + \text{CaCl}_2$ are given.

In a series of experiments of short duration on the absorption of NH_4 and NO_3 by the plants from solution—either from NH_4NO_3 alone, from ammonium chloride, or from a weakly acid solution of $\text{NH}_4\text{NO}_3 + \text{HCl}$ or $\text{NH}_4\text{Cl} + \text{HCl}$ —the characteristic physiological acidity of NH_4NO_3 was noticed. This was expressed by the following: 1. A more speedy absorption of NH_4 than NO_3 . 2. The shifting of the reaction toward an increase of acidity on the unacidified solutions. On the acidified solutions (up to a pH 4.0) the first symptom of physiological acidity of NH_4NO_3 infrequently was noticed, although in a slightly less degree than when a neutral reaction was maintained in the beginning. However, the second indication—the increase of acidity—on cultures already acid from the start; in experiments of short duration, was not observed. It is possible that this is due to the speedy absorption by the plants of the free acid added to the medium. On the medium with NH_4Cl and HCl and with a pH of 4.0, there was a noticeable shift toward alkalinity after 1 hour, followed by an acidifying tendency after 24 hours.

The influence of the various plants on the reaction of a complete medium containing NaNO_3 , NH_4NO_3 , or NH_4Cl , with a small amount of KH_2PO_4 was qualitatively somewhat similar. On the nitrate media the general tendency for all plants was to neutralize the original acidity of the solution (pH 5.5); it was, however, not so pronounced with the buckwheat. Legumes were successful in bringing about a reaction with ammonium chloride to pH 3.9–3.6, at which point they died; the grain crops, like oats and corn, brought the acidity down to 3.3–2.9.

The buckwheat tolerated the acidity produced with the ammonium chloride to a greater extent than all the other plants.

For all plants the difference in pH for the media with ammonium nitrate and in mixtures with ammonium chloride was not great—pH 0.3–0.5—within a

period of 3 weeks experimentation. The injurious influences on the first medium appear later and with less rapidity than on the other media.

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SOME COMPARISONS OF THE PROPERTIES OF HUMID-TROPICAL AND HUMID-TEMPERATE AMERICAN SOILS; WITH SPECIAL REFERENCE TO INDICATED RELATIONS BETWEEN CHEMICAL COMPOSITION AND PHYSICAL PROPERTIES

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In the course of a recent reconnaissance of Central American soils two quite distinct classes of upland clays were encountered. The types comprising one class are friable, freely permeable to water, resistant to erosion, and often show faint profile zonation; whereas the types comprising the other class generally are plastic or stiff, much more impervious, and show better profile zonation. The older concept that the physical properties of soils are largely the resultant of the varying percentages of sand, silt, and clay would not explain the different behaviors of these two classes of soils, since a number of the types of essentially the same texture have shown opposite physical properties. Some of them, although containing an extremely small amount of gritty material, are as friable as light sandy loam, whereas others of similar texture are very stiff.

This paper correlates the friability and plasticity of certain heavy clay soils as determined by field methods with the $\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3}$ ratio of the same soils obtained by chemical analyses made in the laboratories of the Bureau of Soils.

The analytical results cited show the composition of the whole soil and not that of the colloidal constituent alone, but since these soils are very heavy and undoubtedly high in colloidal content, it is believed that the results may be accepted for the purposes of this paper as essentially equivalent to the results that would be obtained by separating and analyzing the contained colloids.

It has been found that the colloidal materials extracted from different soils vary widely in their chemical compositions (14) and in their physical properties (1, 6, 13). Moreover, it appears from recent work (2) that the physical properties of the colloidal material are fairly well correlated with the chemical composition, as expressed by the molecular ratio $\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3}$.

SOME RELATED INVESTIGATIONS AS RECORDED IN THE LITERATURE

Van Bemmelen (15, 16) considers the end-product of lateritic weathering as silica-free alumina; but states that the agents and conditions which cause lateritization, whereby the ratio of silica to alumina is lowered to 1:3 to 1:0,

in contradistinction to ordinary weathering, are not understood. He observes that ordinary and lateritic weathering go on together in some regions, that the former never goes over into the latter under certain conditions and climates, whereas under still other conditions it goes over wholly or in part. He further observes that the heavy clay soils of Holland with a silica : alumina ratio of over 2 are highly plastic, whereas the lateritic clays of Java with a silica : alumina ratio approaching 0 have no plasticity.

Hardy in studying the significance of the shrinkage coefficient of "clays and soils" (7) ascribes the high ratio of Al_2O_3 plus Fe_2O_3 to SiO_2 for certain red soils from Dominica and Barbados to their "lateritic nature," and observes that these types probably owe their special physical characters mainly to the presence of colloidal aluminum hydroxide. He further states that the low ratio of Al_2O_3 plus Fe_2O_3 to SiO_2 for certain types from Montserrat and Antigua indicates that the colloidal material in these types resembles more that contained in soils of temperate regions. He concludes that red lateritic soils, rich in alumina hydrogel, appear to possess relatively low vesicular water contents, and, in consequence, to exhibit low shrinkage coefficients. He believes that the colloidal matter of soils of different origin and chemical composition is specific in certain of its properties and that many of the apparent anomalies in the behavior of soils may be satisfactorily explained by differences in the physical constants in the colloids. From his research on the maximum water-retaining capacity of "colloidal soils" (8) he finds that West Indian "red lateritic soils," whose colloidal content is described as being composed mainly of the hydrogels of alumina and of ferric oxide, exhibit remarkably low volume expansion on wetting.

Joseph (9) finds a certain correlation between the imbibitional water-holding capacity of a number of Sudan clay soils and their chemical composition. Red soil with a silica : alumina ratio of 2.85 showed a very much lower capacity in this respect than the other types, which consist of brown alluvial, brown loessial, and blue loessial types, with silica : alumina ratios ranging from 3.77 to 4.77. He found the plasticity of the colloids in "slate-blue clay" from the upper Nile very high and that of the colloids taken out of red subsoil from Mongalla, very low. In his work on a number of tropical and temperate zone clays he points out (10) an important characteristic in the silica : alumina ratio of the clay separates, noting that this ratio seems connected with essential "clay" properties, being low in non-plastic and high in plastic materials.

It is said to be common knowledge among the Hawaiian sugar plantation operators that Hawaiian clays have radically different physical properties from those of England and the United States—that they do not scour the mold-board of plows well and are generally friable under all conditions. Maxwell's investigations on Hawaiian soils (11) show that most of the soils are low in silica and high in iron and alumina, the average molecular ratio of silica to iron plus alumina being about 0.9.

PROPERTIES OF CENTRAL AMERICAN SOILS

Large areas of well-drained upland soils occurring in the humid parts of Central America have a much higher content of clay and show much greater friability than commonly characterize the finest textured upland types of humid United States. This is true even for many tropical areas having predominantly sloping topography. Presumably the soil of these sloping situations has not lain undisturbed long enough to have had exerted upon it the fullest possible effect of oxidation, hydration, and leaching, such as might be expected on uneroded flats. Wherever erosion has kept such close pace upon rock decay that incompletely decomposed fragments of the parent material are fairly abundant at shallow depths the condition generally may be construed as reflecting a stage of weathering somewhere short of mature soil development. This view may need modification in some instances, as for example, where particles and fragments of highly resistant rocks, such as quartz and agate, are present in considerable amounts through the soil profile.

Notwithstanding the usual sloping features of the region and the more or less conformity as regards soil immaturity in some situations, the products of weathering, in case of the clay types in particular, are profoundly different over extensive areas from those of similar texture usually found in like positions in the wet temperate zone, taking the United States as a representative region for comparison. In this part of the tropics the soils either have undergone more intense weathering or they have undergone changes unlike or partly unlike those that have taken place under average conditions at the more northerly latitudes. The influence of the parent rocks often can not be seen in anything like the same degree encountered in the hilly parts of humid United States, although close relation does exist locally between parent rock and derivative soil, as will be pointed out below.

With a constantly warm temperature and long periods of heavy rainfall, weathering in the tropics has had a much stronger leveling effect upon soil character in this region; rocks have decomposed to greater depths and much more completely in that part of the profile above the zone of visible continuing decay; clays of marked uniformity have developed over large areas and have become exceedingly fine grained; exceptional friability and permeability have resulted; and susceptibility to erosion has been greatly minimized. Soils of clay texture are largely in the predominance over the uplands, except in the vicinity of active or recently active volcanoes. Clays seem to be the normal regional soils, as much so as sandy types are the usual soils found in the coastal plain of southeastern United States.

In extensive areas from Guatemala to Colombia the soil consists of red, buff, and ocherous-yellow (mostly red) clay, showing frequently no conspicuous physical difference from place to place, except that some areas are more friable than others, even though there is wide variety in the underlying rocks, including the basic igneous group and the sedimentaries, such as limestone, shale, and

claystone. It is not meant that there are not widely different soil types within the region. Actually there are a considerable number of variations, but many of these owe their peculiarities to such obvious local conditions as immaturity of weathering, imperfect drainage and, in the more eroded situations, to the lithologic nature of the parent material. As a rule quartz or other gritty particles can not be detected in the clay soil referred to by ordinary field examination, or only small amounts can be found; but in those localities where granitic rocks and the mica schists are abundant, as in northern Honduras, fragments and particles of quartz and flakes of mica are fairly common in the shallow soils. In the latter types comparisons of the ratio of silica to iron plus alumina can not be made properly in all instances with the corresponding ratios for the clays containing little or none of these larger mineral fragments. Some of the physical variations referred to have a pronounced tendency, with advanced weathering, in the direction of:

- (a) Greater friability and permeability than is commonly found in fine-textured soils of similar origin in the temperate zone, as already pointed out; (b) the development of uniform red, yellow, and buff colors; and (c) exceptional profile uniformity.

Similarly the chemical-variations show a tendency under advanced weathering toward an end product having relatively low contents of silica and of the bases, CaO, MgO, Na₂O, and K₂O, and comparatively high contents of iron and alumina. This refers to the well-drained older types.

A striking difference from humid temperate-zone soil conditions is seen in the frequent faint development in the direction of sharply differentiated soil layers or horizons through the vertical section, even where the soil is deep. As a rule the dominant soils, the red clays, have

- (a) A surface layer, ranging from about $\frac{1}{2}$ to 3 or 4 inches in thickness, in which organic matter from vegetation has slightly darkened the red soil, although there are places where scarcely any top soil of this kind is observable. Beneath this faintly developed surficial zone is found (b) red clay which is essentially uniform to depths ranging from about 2 to 8 feet; at which point the clay (c) is often splotched or streaked with material of yellowish, bluish-gray, and whitish or cream colors, often accompanied by soft partly decayed rock material.

There are in these red clays generally no important textural differences between a and b, and often very little or none between a, b and c; and the divisional lines are rarely sharp, the material of one section grading into that of another. Frequently the light and yellowish streaking and mottling of section c represents freshly decayed or partly decayed rock materials of varying character, in which oxidation, leaching, etc. have not advanced to the same stage as in the red soil above. The soil of section c really represents, in a great many instances, what might be designated a secondary or tertiary product of weathering from the parent rock, in that the primary product of weathering usually shows less complete obliteration of the granular character of freshly disintegrated rock. Sections a and b, in other words, represent more nearly

the true soil in the sense of thorough decomposition of practically all of the parent rock material.

This faint zonation or lack of development of obvious horizons through the profile is a common characteristic of large areas of soil not only in Central America but also in parts of the West Indies and northern South America. This seemingly is due, in part at least, to a weakened efficiency in processes of elutriation and eluviation resulting from the peculiar nature of the fine particles formed under wet tropical conditions, a considerable proportion of which has been found to be of a colloidal nature. That the fine material clings together to form clusters from which the individual grains are not readily detached by water to become suspended and moved through the soil mass is evidenced by the physical properties of the soils, such as a highly permeable or granular structure through which water passes rapidly; and the usual rapidity with which the material, when suspended in water by violent agitation, falls out of suspension.¹ Thus there is little opportunity for concentration of clay in the sublayers to form zones of heavier texture than those above, from which the finer particles under dissimilar climatic conditions might have been moved downward by percolating water. In the absence of strongly effective elutriation and eluviation the comparatively coarser textured surface soils so common to humid temperate regions fail to develop over much of the country under discussion; and without effective processes of this nature there would seem to be *a priori* no possibility of developing heavier sub-layers, such as are also common to many areas of smooth topography in the temperate zone, except as they are formed through decay of parent material that weathers directly into soil of fine texture.

The content of flocculent colloidal material of the kind referred to is prevailingly higher in some parts of the humid American tropics than in others. This appears to be due partly to an exceptionally heavy rainfall and good under drainage, and partly to the character of the parent material.

In the very humid eastern part of Costa Rica there is considerable soil so open natured by reason of the aggregated or flocculated fine material that rain water rapidly passes into and through the ground, and the soil exhibits such slight stickiness that the land can be plowed during or immediately after a heavy rain to form a very granular tilth (plate 1).

This Costa Rican type—Colombiana clay (tables 1 and 5)—is of exceedingly fine texture, containing only 0.7 per cent of particles coarser than silt; yet it is as friable as the mellowest loam, and in the practical sense is not susceptible to erosion (3, 4). It is derived from old outwash material coming from basic igneous rocks and volcanic ejecta on the slopes of the adjacent cordillera. In this region the rainfall is very heavy—209 inches at Sarapaquí.

¹ Colloid extracted from a sample of extremely friable tropical soils of clay texture from Costa Rica has exhibited considerable immunity from miscibility with water, requiring intimate rubbing of the material to bring about dispersion. The material falls out of suspension quickly.

TABLE I
Chemical analyses of striated tropical soils

TYPE AND COUNTRY	SAMPLE NUMBER	DEPTH inches	ORGANIC MATTER						NATURAL GASES FROM CARBONATE						SO ₂ + FeO ₂							
			SiO ₂	TiO ₂	Al ₂ O ₃	MgO	CaO	K ₂ O	Na ₂ O	Zn	Pb	As	Fe	Co	CH ₄	CO ₂	CO	SO ₂	NO _x	NO ₂	SO ₃	
Spiritito Santo clay, Honduras.....	28126	24-36	41.87	0.69	6.19	32.53	0.04	14.0	18.0	0.71	0.28	0.24	0.09	0	15.63	....	1.90				
Arraiján clay, Panama	{ 30514	0-3	34.57	1.67	16.13	25.73	0.36	0.38	0.72	0.09	0.07	0.12	0.39	0	20.39	....	1.60				
	30515	3-30	38.13	1.37	14.59	31.47	0.24	Tr.	0.71	0.14	0.02	0.07	0.09	0	13.25	....	1.60				
	30516	30-40	40.48	1.28	14.53	30.25	0.15	Tr.	1.62	0.35	0.04	0.02	0.03	0	10.98	....	1.70				
	30517	40-52	41.08	1.23	15.66	30.97	0.12	Tr.	0.93	0.70	0.32	0.02	0.02	0	9.04	....	1.70				
Turrialbas silty clay, Costa Rica.....	{ 30557	0-14	33.85	2.02	11.64	33.78	0.08	0.32	0.22	0.26	0.39	0.56	0.19	0	17.07	....	1.40				
	30558	14-32	30.28	2.37	16.13	34.02	0.20	0.12	0.23	0.32	0.19	0.38	0.54	0.09	0	15.88	1.10				
	30559	32-60	28.99	2.51	16.83	33.79	0.22	0.20	0.32	0.42	0.25	0.41	0.51	0.08	0	15.54	1.10				
	30560	60-90	30.63	2.55	16.77	34.33	0.19	0.30	0.32	0.28	0.52	0.48	0.07	0	14.43	....	1.20				
Aragon clay, Costa Rica.....	{ 30567	0-11	28.65	2.06	13.20	33.79	0.07	Tr.	0.08	0.15	Tr.	0.19	0.26	0	21.81	7.21	1.10					
	30568	11-20	30.04	1.89	12.93	34.79	0.04	0.10	0.28	0.25	0.27	0.32	0.15	0	18.95	3.45	1.20					
	30569	20-40	30.40	1.99	13.82	35.79	0.04	0.10	0.13	0.19	0.18	0.31	0.07	0	17.62	1.83	1.15					
	30570	40-96	26.49	1.99	14.44	38.16	0.03	0.10	0.15	0.17	0.20	0.30	0.04	0	17.82	0.59	0.90					
	30571	96-132	28.65	2.06	12.21	47.88	0.03	0.10	0.19	0.19	0.15	0.32	0.04	0	18.45	0.85	0.85					
	30572	132-144	25.25	2.08	14.10	39.05	0.03	0.10	0.17	0.23	0.13	0.35	0.04	0	18.32	0.67	0.90					
	30573	144-162	9.77	2.13	16.95	45.98	0.10	0.10	0.18	0.12	0.48	0.02	0	25.00	0.71	0.30						
	30574	162-202	5.00	2.62	19.31	46.89	0.18	Tr.	0.20	0.05	0.05	0.56	0	25.14	0.47	0.15						
	30575	at 35 ft.	38.21	2.08	14.08	32.00	0.29	Tr.	0.20	0.10	Tr.	0.28	0.03	0	12.69	....	1.60				

Columbiana Clay, Costa Rica.....	{ 30584	0-24	18.79	2.37	16.30	38.48	0.34	Tr.	0.37	0.23	0.09	0.40	0.17	0	22.52	3.82	0.65	
	{ 30585	24-65	17.92	2.22	14.52	37.34	0.23	Tr.	0.37	0.23	0.09	0.48	0.13	0	26.48	7.76	0.65	
	{ 30586	65-108	26.77	2.06	16.01	34.66	0.37	1.37	3.06	0.14	0.17	0.59	0.01	0	14.92	....	1.00
Uruca loam, (Sub.), Costa Rica.....	{ 30608	92-102	40.33	1.21	12.02	27.15	0	16.1.62	3.64	0.36	0.58	0.24	0.03	0	11.97	....	1.96
Cukra clay, Nicaragua.....	{ 30644	0-7	29.64	3.74	17.05	25.00	0	20.0	31.0	29	0.25	0.23	0.55	0.43	0	22.10	1.90
	{ 30645	7-60	31.57	2.94	19.83	28.00	0	14.0	27	0.22	0.24	0.21	0.52	0.12	0	16.50	1.30
Average.....		....	29.30	....	14.91	34.28	....	0.24	0.62	0.25	0.21	....	....	....	....	....	1.25

TABLE 2
Chemical analyses of non-friable tropical soils

TYPE AND COUNTRY	SAMPLE NUMBER	DEPTH, inches	NATTS												ORGANIC MATTER, per cent	MOL% $\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$		
			SiO_2 , per cent	TiO_2 , per cent	FeO , per cent	MnO , per cent	CaO , per cent	MgO , per cent	Na_2O , per cent	K_2O , per cent	P_2O_5 , per cent	Zn , per cent	Cu , per cent	Mn , per cent				
Lancatillal clay loam, near Guatemala, Honduras boundary.....	28109	0-8	44.40	1.56	10.89	20.89	0.09	6.17	5.80	0.66	1.55	0.13	0.27	....	9.30	4.01	2.00
	28110	8-18	45.83	1.57	12.15	20.53	0.09	6.07	5.78	0.74	1.35	0.10	0.08	....	5.48	....	2.50
La Francia clay, Honduras.....	28111	0-2	57.59	0.81	5.77	17.26	0.04	6.74	0.70	1.89	0.41	0.12	0.46	....	13.57	6.73	4.60
	28112	2-36	62.06	0.75	5.95	18.80	0.05	0.45	0.65	1.75	0.43	0.14	0.22	....	8.57	3.35	4.60
Talladega clay, Honduras.....	28123	0-3	65.00	0.74	4.47	14.48	0.29	0.32	0.43	1.38	1.24	0.06	0.17	....	11.22	5.92	4.60
	28124	3-20	62.77	0.72	5.98	19.88	0.08	0.15	0.44	1.91	1.24	0.04	0.05	....	6.33	1.50	4.50
Toscentales clay, Honduras.....	28148	0-36	67.00	0.53	2.77	12.25	0.04	6.97	1.85	2.85	1.27	0.60	0.03	....	4.36	2.36	8.10
	28154	6-36	77.00	0.76	2.43	9.75	0.04	1.06	0.63	1.76	1.00	0.06	0.14	....	5.90	....	11.60
Chandler loam, Honduras.....	30522	0-6	47.48	0.95	10.67	17.04	0	17.19	81.97	0.32	0.13	0.14	0.66	0	19.30	....	3.40
	30523	6-22	49.49	1.06	11.85	19.25	0	18.19	93.22	0.23	0.28	0.11	0.10	0.33	0	13.78	3.10
Santa Rosa clay, Panama.....	30533	0-9	41.27	1.67	11.87	25.89	0	14.25	0.50	1.11	0.76	1.45	0.26	0.15	0	13.65	2.10
	30534	9-13	41.37	1.68	13.53	26.31	0	19.19	1.66	0.59	0.71	1.20	0.25	0.11	0	12.33	2.00
Ururu clay loam, Costa Rica.....	30535	13-40	42.40	1.86	13.39	27.60	0	16.09	0.46	0.73	0.96	0.21	0.05	0	11.64	....	2.09
	30356	40-47	44.20	1.39	11.55	28.40	0	17.08	1.81	0.88	0.48	0.14	0.03	0	11.65	....	2.10
Aragon clay, Costa Rica.....	30576	at 37 ft.	43.51	1.03	7.13	27.85	0	17.0	1.79	1.27	1.10	0.46	0	0	9.31	....	2.50

Bluefields clay, Nicaragua.....	30653 30654	0-8 8-40	59.01 47.78	1.86 1.24	7.18 10.24	14.59 25.39	0.040 0.010	0.370 0.290	0.540 0.500	0.250 0.500	0.080 0.240	0.26 0.08	0 0	15.24 13.20	... ... 5.20 4.00	
Vinces clay, Ecuador.....	31222 31223 31224	0-14 14-42 42-120	48.57 46.38 48.91	1.42 0.99 1.11	11.31 10.46 10.37	11.34 29.03 27.23	24.20 0.050 0.020	0.260 0.180 0.150	0.720 0.700 0.770	0.630 0.600 0.717	0.370 0.410 0.400	0.130 0.14 0.02	0 0 0	11.95 12.18 11.34	2.60 0.50 0.22	2.60 2.20 2.40
San Pablo clay, Canal Zone.....	31225 31355 31356	120-160 0-7 7-48	52.32 58.35 49.50	0.96 1.56 1.34	10.26 12.37 12.56	23.80 13.67 22.59	0.220 0.240 0.052	0.320 0.620 0.410	1.230 0.510 0.920	0.400 0.280 0.320	0.170 0.080 0.26	0.001 0.29 0.03	0 0 0	9.29 12.31 0.82	0.37 4.55 10.17	2.90 4.00 2.80
Average.....		.....	52.33	.....	9.53	21.28	.....	1.55	1.32	0.90	0.73	.....	.....	.....	3.71	

TABLE 3
Average and range of silica, iron and alumina, total bases, and molecular ratio of silica to iron and alumina in 24 friable and non-friable soils

	AVERAGE SiO_2	RANGE SiO_2	AVERAGE $\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$	RANGE $\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$	AVERAGE $\text{CaO} + \text{MgO} + \text{K}_2\text{O} + \text{Na}_2\text{O}$	RANGE $\text{CaO} + \text{MgO} + \text{K}_2\text{O} + \text{Na}_2\text{O}$	AVERAGE MOLES $\frac{\text{SiO}_2}{\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3}$	RANGE MOLES $\frac{\text{SiO}_2}{\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3}$
Friable....	29.30	5.00-41.87	49.19	31.19-66.72	1.32	0.13- 6.55	1.25	0.15- 1.96
Non-friable.	52.33	41.27-77.00	30.81	12.18-38.78	4.50	0.85-17.17	3.71	2.00-11.6

TABLE 4
Physical composition

FRIABLE GROUP				NON-FRIABLE GROUP			
Sample number	Sands and fine gravel	Silt, clay and colloids	Colloids by absorption	Sample number	Sands and fine gravel	Silt, clay and colloids	Colloids by absorption
	per cent	per cent	per cent		per cent	per cent	per cent
28126	23.1	76.9	....	28109	53.3	46.7	....
30514	1.5	98.5	66.5	28110	64.7	35.3	....
30515	0.7	99.3	82.0	28111	14.7	85.3	....
30516	0.5	99.5	91.0	28112	11.7	88.3	....
30517	0.6	99.4	86.0	28123	26.4	73.6	....
30557	1.3	98.7	64.7	28124	21.1	78.9	....
30558	3.1	96.9	61.2	28148	19.5	80.5	....
30559	4.4	95.6	59.5	28154	48.0	52.0	....
30560	6.0	94.0	58.3	30522	4.9	95.1	90.4
30567	2.9	97.1	75.4	30523	7.3	92.7	90?
30568	2.5	97.5	77.3	30533	17.1	82.9	67.2
30569	1.1	98.9	80.3	30534	5.6	94.4	74.5
30570	1.6	98.4	81.3	30535	5.0	95.0	83.2
30571	1.2	98.8	86.1	30536	7.8	92.2	71.0
.....	....	....	....	30576	....	....	....
30572	1.7	98.3	87.2	30653	8.0	92.0	55.0
30573	2.4	97.6	49.7	30654	2.6	97.4	82.1
30574	4.3	95.7	36.6	30655	1.2	98.8	66.0
30575	4.4	95.6	41.7	31222	6.3	93.7	56.2
30584	0.7	99.3	71.0	31223	2.8	97.2	74.8
30585	1.2	98.8	66.9	31224	3.0	97.0	67.3
30586	4.9	95.1	90.5	31225	4.6	95.4	68.6
30608	22.6	77.4	75?	31355	....	....	....
30644	5.5	94.5	79.9	31356	....	....	....
30645	4.9	95.1	87.6	....	....	....	....
Average.....	....	71.9	....	....	....	....	72.7

Another very friable clay found near Turrialba in eastern Costa Rica—Aragon clay (tables 1 and 5)—although showing no important textural differ-

entiation throughout that part of the profile above the section containing a small amount of incompletely decomposed rock particles, beginning at 13½ feet (table 4), does show some color zonation (table 5). In this type it will be observed that there have been considerable reduction in the amount of silica present and an increase of alumina and iron from the surface down into the horizon containing partly decomposed rock particles (table 4). Within a depth of 13½ feet the diminution of silica has been from approximately 30 per cent to 5 per cent (table 1); and the increase of alumina and of iron (Fe_2O_3) from 34 to 47 and from 13 to 19 per cent, respectively. The bases (CaO , MgO , K_2O , and Na_2O) have decreased from an average of 0.6 per cent in the surface 40 inches, to 0.3 per cent; phosphorous (P_2O_5) has increased from 0.19 to 56 per cent; and organic matter has decreased from 7.2 to 0.47 per cent.

DEGREE OF WEATHERING

This type of weathering indicates that silica leaches from some land areas at a relatively faster rate than iron and alumina.²

Weathering activities of the nature described above seem to be responsible for the development of the peculiar soil conditions found in these regions, and this type or *degree of weathering* undoubtedly accounts for the abundance of soils in the humid tropics, which have been described as laterites or as being lateritic.

Clarke says in this connection (5, p. 488-490):

In tropical and subtropical regions the processes of rock decay are often carried further than is usually the case within the temperate zones. The leaching is more complete, the silicates are more thoroughly decomposed, and the residues are richer in hydroxides. In India, for example, large areas are covered by a red earth known as laterite, which in some cases is undoubtedly a derivative in place of preexisting rocks, such as granite gneiss, basalt or diorite. In other cases the laterite is detrital in character and far distant from its place of origin. The term has been vaguely used, and as employed by different writers it has meant very different things. It has been applied to ferruginous clays, sediments, beds of iron ore, and products of volcanic action, and its formation has been attributed to variety of causes

² Clarke's data (5, p. 115) seem to show that the rivers of North America carry to the sea about 13 times as much silica as iron and alumina, whereas the lithosphere contains somewhat less than 3 times as much silica as iron and alumina. As to what degree these results may need to be modified by possible failures to measure the amount of various constituents carried in colloidal suspension (17) is not known.

Some soils show under the microscope the presence of secondary quartz. This is true of the highly quartzose soil occurring in the sandy savanas of Northeastern Nicaragua (determined by W. H. Fry, Bureau of Soils). Just what conditions are most favorable to leaching out of silica and to development of secondary quartz, and as to what the quantitative relation is between removal and accumulation of this material, are facts which are probably unknown. Merrill has pointed out (12) that in certain rocks, such as the siliceous crystallines, diorite, and some of the diabases, iron and alumina are less subject to removal by leaching than silica.

It has been shown that soil colloids of dry regions are higher in silica than the colloids of wet-region soils (14).

. . . . whatever its derivation true laterite is essentially a mixture of ferric hydroxide, aluminum hydroxide and free silica in varying proportions. To laterite in situ this statement applies very closely; detrital laterite is usually contaminated by admixtures of clay. Just as in the formation of kaolin, the process of lateritization may be complete or partial; the typical product appears only when the alteration of the parent rock has gone on to the end. Then the silicates seem to be completely broken down, whereas in kaolinization a stable, hydrous silicate remains. A careful reduction of the data leads to the supposition that the residual substance is a mixture of gibbsite, AlO_3H ; diaspose, AlO_2H ; and limonite, $\text{Fe}_2\text{H}_6\text{O}_9$. In short, laterite is identical in type with bauxite, and is merely an iron-rich variety of the latter. Between aluminous beauxite and the iron compound limonite all sorts of mixtures may occur.

There is much in the literature that relates to lateritic soils, but a discussion of this is not deemed pertinent to this paper which does not propose to define lateritic soils, although dealing with material some of which appears to correspond closely with soils that some investigators have described as being lateritic.

SIGNIFICANCE OF THE SILICA: IRON PLUS ALUMINA RATIO

If the soils, whose compositions have been determined, be grouped into two groups so that the members of one group will show a molecular ratio of silica to combined alumina and iron oxide less than 2 and the other more than 2, it is found that such a grouping is approximately identical with one made on the basis of friability and plasticity—the non-friable group has a ratio greater than 2, the friable group less than 2.

In using the ratio $\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3}$ for the whole soil it is admitted as an obvious

fact that the relation of the physical properties of the soil and its composition may be of significance only for those classes which are high in clay and low in such discrete particles as quartz. The highly quartzose soils mostly belong in the very sandy group, which normally is characterized by high friability—unless it should be better in this instance to use the term “incoherency” or “looseness” as distinguished from friability, in that the former term implies ready separation of the individual grains, whereas the latter term implies aggregation of the particles where the binding force is short of a state of marked hardness or consolidation. To what limit the content of intact mineral fragments large enough to exert a pronounced physical influence may extend without causing too great vitiation in the significance of the comparisons has not been determined, and need not be insofar as it vitally affects the meaning of indicated trends in soils of the kind found in many parts of Central America, since it is known that many of these are extremely low in gritty material. Most of the types under discussion contain no visible quartz or other hard grains. All but two of the samples of the friable soil group contain less than 7 per cent of sands, four have less than 1 per cent, and the average is 2.6 per cent, not including the two samples referred to, which contain approximately 23 per cent each (see table 4). Probably there is not much free primary quartz in the

finer constituents, since many of the soils come from basic igneous rocks, containing little or no quartz. Mineralogical analyses of the surface and sub-layers of the Arriaján clay (samples 30514 and 30515) have shown that the determinable minerals constitute only a trace of mica in the silt separate. Also only a trace of mica was found in the Columbiana clay, which is one of the most representative members of the group of friable soils.

Returning to the profile of the Aragon clay (see table 1) we find that the material of the entire section (samples 30567 to 30573 inclusive) above the zone of extremely low silica content is very friable and permeable. Below the zone of lowest silica, the material (sample 30575) shows what appears to be the effects of less intensive weathering, as measured by the silica : iron plus alumina ratio, that is 1.6 as against an average of .55 in the four horizons above. Farther down, the material of the "rotten rock" zone (sample 30576) indicates still greater diminution in the intensity of weathering, and according to the ratio employed above, belongs in the class of soil materials having properties opposite to those of the friable group, although this particular material is not very plastic and with removal of the discrete particles probably would fit into the friable group.

So deeply has weathering extended in the locality that the exact nature of the parent rock can not be readily determined in many places, although it probably belongs to the basic igneous group, along with some admixture of volcanic ash. In any case a study of the profile of the Aragon clay indicates that much silica has been lost in the weathering of the material lying above the zone containing an appreciable amount of incompletely decomposed parent rock particles, whereas the iron and alumina have shown a gain, both in proportion to the silica of this highly weathered material and to the amount of iron and alumina contained in the less modified zone beneath. Just why there is a decrease of silica downward is not understood. Accumulating colluvial material may have had something to do with this, or optimum conditions for removal of the silica and accumulation of iron and alumina may have existed in the lower layers. The Columbiana soil which is a good illustration of intense weathering, does not show a similar downward decrease of silica and an increase of iron and alumina (see table 1).

GROUP I: FRIABLE SOILS

Table 1 shows the chemical composition of 24 fine-textured soils (including substrata) from humid tropical Central America, grouped on the basis of a molecular ratio of $\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3}$ = less than 2. Compared with most of the upland clay soils of humid United States, all of these soils are distinctly more friable in all parts of their profiles, and they are much more permeable and resistant to erosion. Compared with one another, those that are highest in iron and alumina and lowest in silica are the more friable, permeable, and resistant to erosion. The material of the most friable or the most weathered layers shows no visible swelling or shrinking at the extremes of moisture content.

TABLE 5
Physical properties, parent material, and drainage of friable types

Type and Locality	Sample Number	Position	Underlying Material	Depth inches	Color	Consistency	Drainage
Espiritu Santo clay. Top of Espiritu Santo Mts. 2 mi. N. Espiritu Santo, Honduras	28126	Nearly flat (About 4000 ft.)	Mica schist	24-36	Yellowish-brown	Moderately friable, brittles (moist)	Good
	30514	Gentle slope (480 ft.)	Igneous basic (dio- ritic) Igneous basic (dio- ritic)	0-3 3-30	Brownish Red	Slightly crumbled (dry)	Good
	30515		Igneous basic (dio- ritic)	30-40	Purplish, grayish and yellowish	Slightly friable to moderately stiff, about like subsoil of Mecklenburg soils (moist)	Good
Arraiján clay. Arrai- ján, R. P.	30516		Igneous basic (dio- ritic)	40-52	Purplish and grayish	Friable, contains some soft partly decayed rock (moist)	Good
	50317		Igneous basic (dio- ritic)	0-14	Brown	Friable, considerable partly decayed rock (moist)	Good
	30557	Flat, lower slope	Slope-base material— probably volcanic ash and igneous	14-32	Brown and rusty brown	Friable (moist)	Good
Turrialba silty clay. Turrialba, C. R.	30558		Slope-base material— probably volcanic ash and igneous	32-60	Dark-brown	Friable (moist)	Fairly good
	30559		Slope-base material— probably volcanic ash and igneous			Friable (wet)	Imperfect

							Poor— near water- table
{	30560	Slope-base material— probably volcanic ash and igneous	60-90	Black and rusty- brown and con- tains segregated iron	Friable (saturated)		
30567	Gentle slope (2,100 ft.)	Probably feldspar porphyry and vol- canic ash	0-11	Brown	Crumbled-fine fragments (dry)	Good	
30568		Probably feldspar porphyry and vol- canic ash	11-20	Yellowish-brown	Friable (dry)	Good	
30569			20-40	Ocherous yellow	Very friable (slightly moist)	Good	
30570		Probably feldspar porphyry and vol- canic ash	40-96	Ocherous yellow, some soft whitish particles	Very friable (moist)	Good	
30571		Probably feldspar porphyry and vol- canic ash	96-132	Ocherous yellow, some soft whitish particles	Very friable (moist)	Good	
30572	Aragon clay. 1 mi. West Turrubá, C. R.	Probably feldspar porphyry and vol- canic ash	132-144	Buff-colored	Compact, friable (moist)	Good	
30573		Probably feldspar porphyry and vol- canic ash	144-162	Reddish-yellow; some whitish and greenish soft de- cayed rock	Friable (moist)	Good	
30574		Probably feldspar porphyry and vol- canic ash	162-202	Mainly greenish and whitish. Appear- ance of decayed rock, but decom- posed and soft; same material to 35 ft.	Friable (moist)	Good	

TABLE 5—Continued

TYPE AND LOCALITY	SAMPLE NUMBER	POSITION	UNDERLYING MATERIAL	DEPTH inches	COLOR	CONSISTENCY	DRAINAGE
					At 35 ft.	Brittle (moist)	Good
Aragon clay. 1 mi. West Turrubalba, C. R.	30575		Probably feldspar porphyry and vol- canic ash	0-24	Chocolate-brown	Friable-crumbly (moist)	Good
	30584	Nearly flat (about 500 ft.)	Outwash from vol- canic and igneous basics	24-65	Slightly reddish- brown	Friable-crumbly (moist)	Good
	30585		Outwash from vol- canic and igneous basics	65-108	Rusty-brown and reddish, with gray- ish specks of soft rotten rock	Crushes easily	Good
Columbian clay. Col- umbiana, C. R.	30586			92-102	Buff; some soft whit- ish particles	Compact in situ; crushes easily (moist)	Good
	30608	Moderately steep (5,300 ft.)	Mainly volcanic ash	0-7	Reddish-brown	Friable (moist)	Good
Urucu loam, deep sub- soil. Laguna, C. R.	30644	Flat (40 ft.)	Diorite	7-60	Reddish-brown	Friable (moist)	Good
	30645		Diorite				Good

This grouping seems to bring out a correlation between chemical composition and physical properties as carefully determined in the field (see table 5). There is a range from 5 to 41.87 per cent of silica and from 31.19 to 66.72 per cent of combined iron and alumina in the group of friable soils (see table 3), and the averages for these constituents are 29.3 and 49.19 per cent, respectively. The extremes of these ranges point to soil properties of opposite characteristics:

(a) To permeable, friable open soils, which show no perceptible volumetric changes with wetting and drying, in one direction—that of low silica and high iron and alumina, and (b) to non-friable, plastic or stiff soils, which shrink and crack on drying and swell to a corresponding degree with wetting, in the other direction—where the ratio of the constituents named are reversed.

Table 5 shows some of the most outstanding physical properties of this group.

GROUP II: PLASTIC SOILS

Using the molecular ratio $\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3}$ = 2 or more, as a dividing line, 24 other upland soils (including substrata) collected from the same humid-tropical region have been grouped into table 2 and designated as a group of non-friable or stiff soils. Most of these are clays, but they range to clay loam and in one case to loam (see table 4). The average content of material coarser than silt in 18 of the samples is 9.4 per cent and the average of the colloids is 72.7, with a maximum range to 90.4 per cent. In the group of more friable soils the average of colloids is 71.9, with a maximum range of 91 per cent.

In the main, these types are stiff and plastic, a few are brittle, and some are friable (see table 6). In some degree the friability of a few of the subsections is due to the presence of incompletely decayed rock particles, including some free quartz; but most of the stiff to plastic soils are as heavy textured as the most friable of the other group. Table 6 shows the most outstanding physical properties of this group.

Taking the subsoil of the San Pablo clay (sample 31356), as an example of extreme plasticity, we find in the field the material to be so extremely dense and impermeable that it retains its intimately associated water almost as tenaciously as if it were water of combination. Under this condition the interstitial space is so choked that there is extreme retardation in the circulation of both water and air. In the dry season a shallow surface layer of this type—that containing a fair supply of organic matter—cracks and recracks to form a loose or fine-fragmental soil, which becomes highly desiccated. Immediately beneath this parched layer the clay is moist and plastic throughout the dry season; yet deep-rooted crops such as orange trees, suffer severely or die on the type because they are unable to take sufficient moisture out of the putty-like clay. All crops wilt, parch, or die, showing unmistakably that the trouble is inadequacy of available moisture.

TABLE 6
Physical properties, parent material, and drainage of types largely non-friable

TYPE AND LOCALITY	SAMPLE NUMBER	POSITION	UNDERLYING MATERIAL	DEPTH	COLOR	CONSISTENCY	DRAINAGE
Lancatilla clay loam. Near Lancatilla, near Guatemala-Honduras boundary	28109	Moderately steep, (about 1,500 ft.)	Hornblende-gabbro	0-8	Dark-brown	Moderately friable (moist)	Good
	28110		Hornblende-gabbro	8-18	Greenish-brown con- taining dark parti- ly decomposed rock	Slightly plastic (moist)	Fair
La Frandia clay. S. La Francia, Hon- duras	28111	Steep (about 2,500 ft.)	Limestone	0-2	Brownish-red	Friable (moist)	Good
	28112		Limestone	0-36	Red	Friable (moist)	Good
Talladega clay. Espi- ritu Santo, Honduras	28123	Steep (about 2,500 ft.)	Mica schist	0-3	Light-brown	Moderately friable, greasy feel (dry); plastic when moist	Good
	28124	Steep (about 2,500 ft.)	Mica schist	0-20	Red	Stiff and brittle; contains some quartz and schist particles (moist)	Good
Tosontales clay. N. Tosontales, Hon- duras	28148	Steep (about 3,500 ft.)	Grano-diorite	0-36	Red	Friable, contains some rock particles (moist)	Good
Chandler loam. N. Tosontales, Hon- duras	28154	Moderately steep	Mica schist	6-36	Yellow	Friable, contains some mica flakes (moist)	Good

Santa Rosa clay. 1 mi. E. Limon, R. P.	30522	Nearly flat (about 200 ft.)	Limestone	0-6	Brown	Slightly crumbly (moist)	Good
	30523	Limestone	6-22	Yellow	Very plastic and sticky (moist)	Imperfect	
Urucu clay loam. 5 mi. N. San Jose, C. R.	30533	Gentle slope (about 4,000 ft.)	Volcanic ash	0-9	Dark-brown	Friable (dry); consider- able grit	Good
	30534	Volcanic ash	9-13	Brown	Coarse-crumbly or small- cloudy (dry); slightly plastic when moist	Fair	
Aragon clay. 1 mi. W. Turrubala, C. R.	30535	Volcanic ash	13-40	Mottled yellowish- brown and buff	Cracks into clods on dry- ing, plastic when moist	Fair	
	30536	Volcanic ash	40-47	Brown	Friable (moist)	Good	
Bluefields clay. Blue- fields, Nicaragua	30576	Gentle slope	At 37 ft. (see table V)		Brittle (moist)	Good	
	30653	Gentle slope (about 90 ft.)	0-8	Light-brown	Plastic (moist)	Medium	
	30654	Diorite and possibly some of the asso- ciated acidic col- bles	8-40	Mottled red and blu- ish-gray	Very plastic (moist)	Poor	
	30655	Diorite and possibly some of the asso- ciated acidic col- bles	40-120	Mottled white and red	Plastic (moist)	Poor	

TABLE 6—Continued

TYPE AND LOCALITY	SAMPLE NUMBER	POSITION	UNDERLYING MATERIAL	DEPTH	COLOR	CONSISTENCY	DRAINAGE
Vinces clay. Vinces, Ecuador	31222	Flattish hillock (about 80 ft.)	Old alluvium	0-14	Brown	Cracked into hard clods (dry); plastic when moist	Fair
	31223		Old alluvium	14-42	Yellowish-brown some gray mot- ting	Plastic when moist	Fair
	31224		Old alluvium	42-120	Mottled bluish-gray and yellow	Plastic when moist	Poor
	31225		Old alluvium	120-160	Mottled yellowish- brown, yellow and bluish-gray, dark segregated iron	Compact	Poor
San Pablo clay. Sum- mit, C. Z.	31355	Flat depres- sion (about 225 ft.)	Probably limestone	0-7	Mottled brown and yellow	Cracks into small hard clods (dry); plastic when moist	
	31356		Probably limestone	7-48	Yellow	Very plastic, sticky and dense (moist)	

This soil is of limestone origin. It occupies a low position of poor drainage. In the wet season it is continuously water-logged and crops on it are seriously damaged by an excess of moisture. Weathering has been restricted to the surficial layer in this poorly aerated material.

The molecular ratio of silica to combined iron and alumina for this type is 4.6 in the soil and 2.8 in the subsoil.

In general this group of soils approximates the physical properties of the San Pablo clay. Outstanding exceptions, as previously noted, appear to be due largely to an excess of hard rock particles; but some of the soils, such as

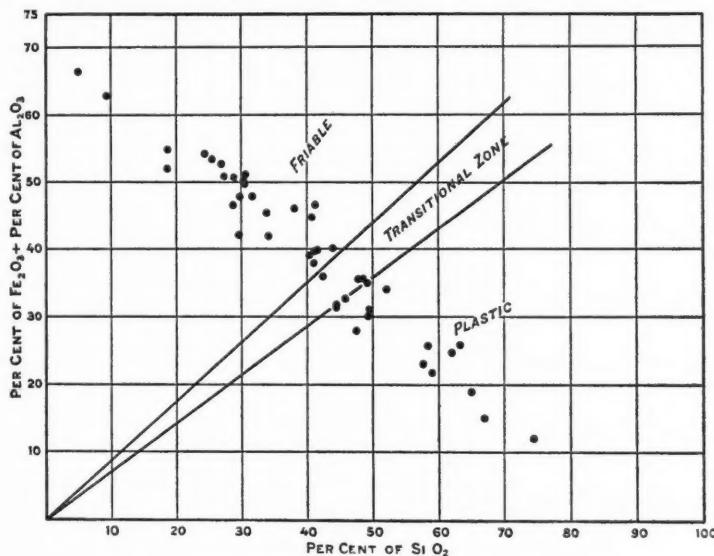


FIG. 1. PERCENTAGE RELATION OF SILICA TO IRON AND ALUMINA

samples 28111 and 28112, show a degree of friability that can not be accounted for solely by the presence of gritty material. If the basis of separating the soils had been on the amount and character of the contained colloids these friable types might have fallen into the opposite group.

Figure 1 graphically represents the relation of silica, by percentage, to iron and alumina, with a gradational zone rather arbitrarily drawn to separate roughly the areas of friable and non-friable soils.

RATIO OF IRON AND ALUMINA TO COMBINED WATER

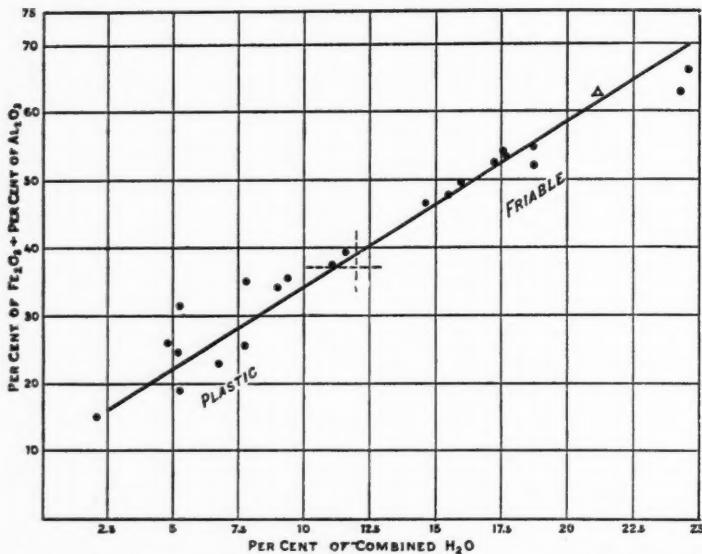
Figure 2, plotted from percentages,³ shows the ratio of iron and alumina to combined water. On the basis of the samples for which the combined water

³ Loss on ignition less CO_2 from carbonates, and less organic matter determined by weighing CO_2 evolved from combustion.

has been determined, the graph indicates that this form of water is proportional to the iron and alumina content. It thus appears that the iron and alumina in these types at least are neither more nor less hydrated in the one group than in the other. Somewhere along the line of ascending values there is a point beyond which the soils are markedly friable and below which they are stiff, but this point seemingly does not necessarily mark any sharp break in the ratio.

CONTENT OF BASES

If the soils of the humic tropics have been severely leached in those types where weathering has been most intense, it would seem the content of lime,



△ Represents sample of extremely lateritic soil from Northern Guam - a red soil with less than 1% silica.

FIG. 2. PERCENTAGE RELATION OF IRON AND ALUMINA TO COMBINED WATER

magnesia, soda, and potash should be relatively low. The average percentage of these four bases found in the friable group is 1.32 and the range is from 0.13 to 6.55 against an average of 4.50 and a range of 0.85 to 17.17 in the group of stiff soils. The maximum range of bases in the former group goes up to 1.95 per cent, with the exception of 3 samples. Figure 3, shows something of the general tendency in the percentage relation of iron and alumina to that of the combined mono- and divalent bases.

It has been shown that the physical properties of colloids vary somewhat with the character and amount of absorbed bases. In arid regions it may be possible that soils with a high content of sodium salts, for example, will show

more deflocculation, plasticity, and imperviousness than the silica : iron plus alumina would indicate.

RELATED NORTH AMERICAN SOILS

Table 7 shows chemical analyses of a number of humid North American red to deep-red upland clay soils derived from rocks of the types corresponding to the parent rocks of many of the tropical soils discussed, such as basic igneous rocks, limestone, and granite. The friability of none of these is developed to the degree encountered in the tropical soils of low $\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3}$ ratios de-

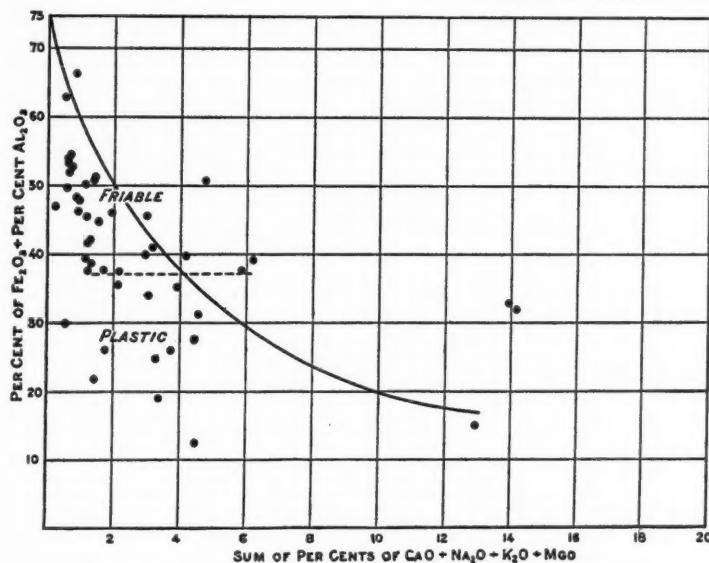


FIG. 3. PERCENTAGE RELATION OF IRON AND ALUMINA TO BASES

scribed above; but the properties of the one having a molecular ratio $\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3}$ equals less than 2, that is the Davidson clay loam, resemble very closely those of the highly friable class of tropical soils. The Davidson clay loam is locally known as "push land" because the crumbly material does not scour well over the moldboard of plows. Exactly the same property is exhibited by the well-defined friable Columbiana clay of eastern Costa Rica. Both types in the moist condition adhere to the plow share apparently more from force of impact than from mere stickiness, since neither soil is especially sticky (the Columbiana clay shows almost no stickiness). The Davidson clay loam is so crumbly that the plow simply pushes it aside instead of turning a more or less firm furrow-slice. The same thing is true of the Columbiana clay.

TABLE 7
Chemical analyses of granite, limestone and basic igneous soils from humid Southeastern United States

TYPE, LOCATION AND PARENT ROCK	SAMPLE NUMBER	DEPTH inches	NATURAL												$\text{Mols SiO}_2 + \text{Fe}_2\text{O}_3$	
			SiO_2 per cent	Al_2O_3 per cent	CaO per cent	MgO per cent	Na_2O per cent	K_2O per cent	P_2O_5 per cent	S_2O_3 per cent	Cl_2O per cent	CO_2 from calcite per cent	CO_2 from carbon per cent			
Mecklenburg clay loam, Mecklenburg County, North Carolina, diorite.....	24004	0-4	46.41	3.68	17.14	21.85	0.46	1.44	0.93	0.48	1.20	0.24	0.11	0	0.53	3.3
24005	4-24	43.30	2.03	15.29	25.02	0.21	1.48	1.76	0.41	0.89	0.25	0.10	0	0.41	2.1	
24006	24-36	46.70	2.03	12.87	25.21	0.16	3.09	2.04	0.27	2.04	0.23	0.06	0	0.33	2.4	
Davidson (stony) clay loam, Talbot County, Georgia.....	A	0-8	38.53	1.71	22.91	24.14	0.09	0.18	0.18	0.11	0.03	0.21	.....	.....	1.7
Diabase parent rock, unweathered.....	B	.....	51.76	1.43	14.16	14.34	0.19	10.66	5.69	0.32	2.09	0.16	.....	.....	.....
Cecil clay loam, Talbot County Georgia.....	D	0-6	52.81	0.96	8.73	26.65	0.01	0.20	0.35	1.23	0.08	0.13	.....	.....	2.7
Gneiss, parent rock unweathered.....	E	.....	73.63	0.46	2.53	13.55	0.02	1.32	0.64	5.30	2.12	0.15	.....	.....	.....
Cecil clay, Mecklenburg County, North Caro- lina, granite.....	15*	0-6	66.49	1.02	7.43	17.11	0.51	0.36	0.31	0.62	0.16	0.17	0	8.06	2.47
16*	6-36	44.15	1.14	16.23	27.58	0.03	0.44	0.09	0.61	0.15	0.15	.....	0	11.83	2.90
Cecil clay loam, Wilkes County, Georgia, schist and gneiss.....	4†	0-9	83.81	0.80	2.97	7.70	0.20	0.28	0.15	0.79	0.43	0.06	0.03	0	2.89	0.56
Decatur clay loam, Jackson County, Alabama, limestone.....	5†	9-18	75.68	0.87	4.21	12.95	0.16	0.43	0.14	0.73	0.24	0.05	0.04	0	5.50	1.08
3*	0-4	79.35	1.15	4.44	8.89	0.07	0.63	0.39	0.67	0.24	0.18	.....	0	4.80	1.96
4*	4-15	74.81	1.28	5.28	12.80	0.05	0.40	0.33	0.75	0.16	0.15	.....	0	4.63	0.93
															7.8	

* U. S. Dept. Agr. Bul. 122.

† U. S. Dept. Agr. Bul. 1311.

It will be noticed that some of the Cecil types approach the less-than 2 silica:iron plus alumina ratio. One of the properties of the Cecil is that it swells but little on wetting and shrinks but slightly on drying, cracks of considerable size rarely being seen, even in highly desiccated sectional exposures. This, as pointed out, is also one of the properties of the highly friable tropical soils. The red limestone clayey soils (Decatur) of eastern Tennessee and northern Alabama are related in their properties to the friable soils of the Tropics, as are also the red "iron-ore lands" of northeast Texas.

Most of the soils of table 7 are much more friable than most of those of the tropical types of high molecular silica:iron plus alumina ratio, not because they contain more gritty material, but for some other reason, which may be due to the effect of more intense weathering. It would be interesting in this connection to compare the very plastic Iredell clay of the Piedmont region of southeastern United States, a basic igneous rock soil, with the similar highly plastic subsoil of the San Pablo clay; but complete chemical analyses are not available for the former type.

This point will not be discussed further than to observe that it indicates that similar processes of weathering are going on in the tropics and in parts of southeastern United States—that the principal difference seems to be not so much in the kind of weathering as in the degree of weathering, that of the humid tropics being much more intense in many instances.

In this connection it may be added, by way of illustration, that the shallow mica-schist soils of Northern Honduras essentially are duplicates, both physically and chemically, of the mica-schist soils (Talledega) of the southern extension of the Blue Ridge Mountains of the United States, and that the highly quartzose soils of the northeastern Nicaraguan "sandy savanas" include soils which are typical of the Florida Flatwoods, such as the St. Johns, Plummer, and Norfolk sands.

GENERAL CONCLUSIONS

It is believed that investigations in this field of soil study hold out promising results, not only from the standpoint of scientific interest, but possibly also from the practical standpoint. Enough has been pointed out to show that all soils of extremely fine texture do not behave physically in the same way. One type of clay shrinks little or none with wetting and drying, and another swells and shrinks greatly. The latter type is of the plastic group of soils which are so impervious in the extreme cases as to have very poor drainage and aeration. It is the clay of this last group that may be expected to give most trouble as subgrade material in building highways, and it is soil of this kind that is most difficult to cultivate. If some ready means could be devised for distinguishing between these types of clay by those not generally familiar with methods of identifying soil types, here might be something of value to the highway engineer in determining the quality of a doubtful clay soil for a road subgrade.

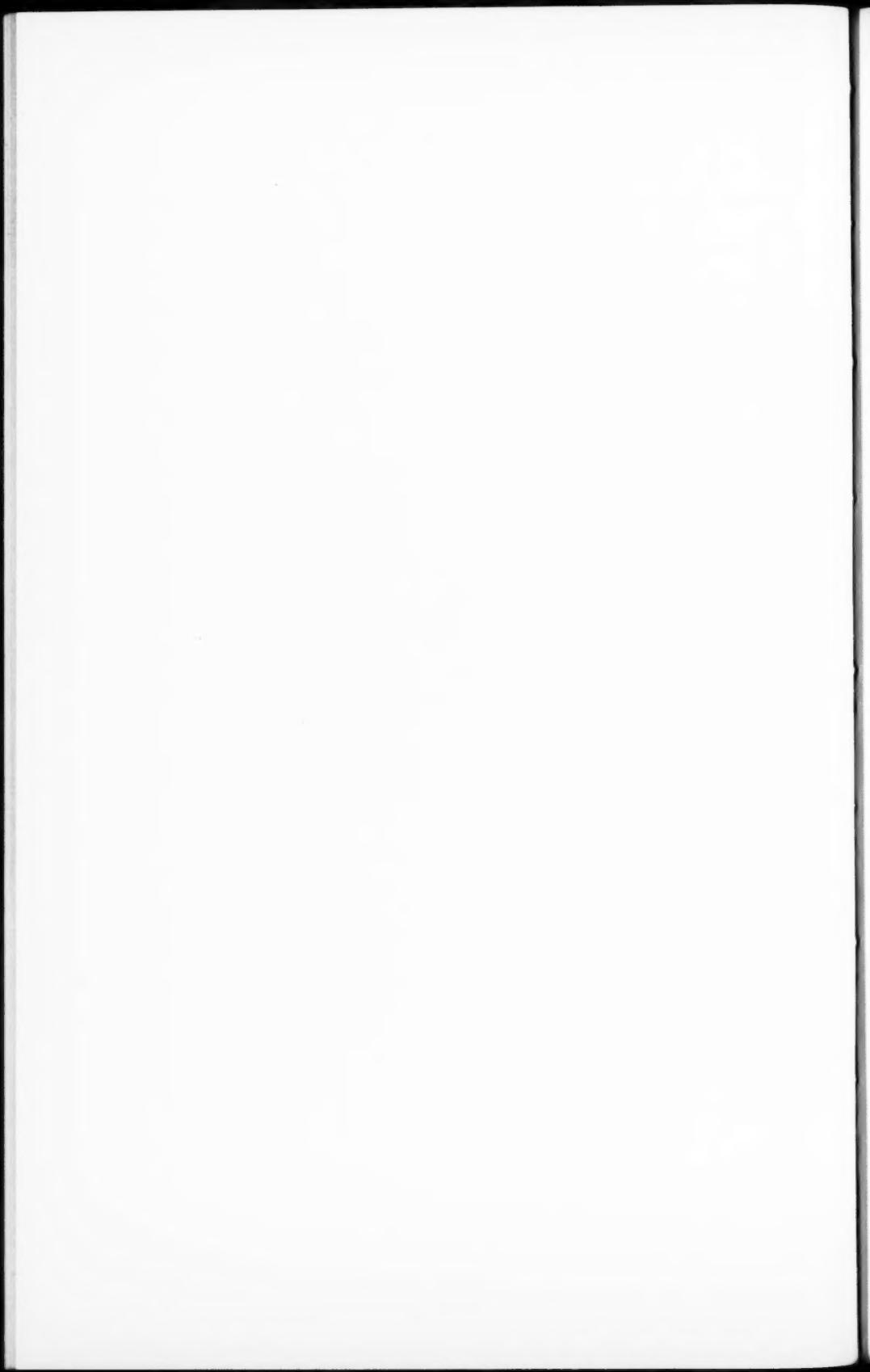
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PLOWING THE COLUMBIANA CLAY IN EASTERN COSTA RICA

The picture was taken about 9 a.m. It had been raining all the morning and every day for a week or more previously, yet this extremely fine-grained soil was turning up into an excellent crumbly tilth and showed almost no stickiness.



INFLUENCE OF FORM, SOIL-ZONE, AND FINENESS OF LIME AND MAGNESIA INCORPORATIONS UPON OUTGO OF CALCIUM AND MAGNESIUM¹

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The immediate and continued effects of economic additions of lime are influenced by several factors. Biological activation may deplete the additions through the formation of the more readily leached neutral salts. The speed and nature of the absorption reactions determine the persistence of carbonates and the formation of non-carbonate residues, the nature of which influences the future availability of the unleached fractions. Recently it has been pointed out (4) that the non-carbonate residues apparently become progressively more tenaciously fixed in the soil through the process of aging. These factors are themselves affected by the relative fineness and solubility of the additions and the method of their incorporation, and by the amount and periodicity of rainfall.

This article deals with the leachings of calcium and magnesium from a fallow brown loam during a 4-year period. Chemically equivalent additions of $\text{Ca}(\text{OH})_2$, four separates, and a composite of both high-calcic limestone and dolomite were made in a 34-tank installation. Influence of *zone of incorporation* is also included as a major consideration.

EXPERIMENTAL

The results given were obtained by analyses of leachings, collection of which was determined by the distribution of annual rainfall. All additions were made at the constant equivalence of 2,000 pounds of CaO , or 3,570 pounds of CaCO_3 , per 2,000,000 pounds of soil, moisture-free basis. In one series the additions were made only to the upper half, or zone, of surface soil, whereas in a second series the additions were incorporated only with the lower half, or zone. Details as to soil, chemical and mechanical analyses of additions, and illustrations of the lysimeter installations are given in a previous

¹ The results were obtained by the use of equipment donated by the American Limestone Company of Knoxville and through a fellowship endowment maintained by the National Lime Association.

² The analyses for the first two years were made by Mr. Hanvey Stanford, while those the third and fourth years were made respectively by Mr. T. D. Harden and Dr. R. M. Barnette, all formerly fellowship assistants at this Station.

TABLE I
Total calcium leached during 4 years from surface-zone additions of 2000 pounds of CaCO_3 and equivalent limestone and dolomite separates
Cu CO_3 -equivalent per 2,000,000 pounds of moisture-free loam soil

TREATMENT	FIRST ANNUAL PERIOD			SECOND ANNUAL PERIOD			THIRD ANNUAL PERIOD			FOURTH ANNUAL PERIOD			TOTAL FOR 4-YEAR PERIOD			4-YEAR INCREASE IN OUTGO OVER CONTROLS		ON BASIS OF ADDITIONS OF CaCO_3 , PER CENT	
	May 10 to Sept. Total	May 10 to Sept. May 31	May 10 to Sept. March 15	May 10 to Sept. Total	May 10 to Sept. May 31	May 10 to Sept. March 15	May 10 to Sept. Total	May 10 to Sept. May 31	May 10 to Sept. March 15	May 10 to Sept. Total	May 10 to Sept. May 31	May 10 to Sept. March 15	May 10 to Sept. Total	May 10 to Sept. May 31	May 10 to Sept. March 15				
Controls.....	128	136	53	40	357	108	43	37	188	69	81	27	177	126	50	176	898	...	...
Ca(OH)_2	240	201	55	47	543	138	43	39	220	79	82	27	188	149	41	190	1141	243	6.8
L. S. 10-20.....	133	127	49	38	347	116	40	35	191	79	107	30	216	169	59	228	982	84	2.4
L. S. 20-40.....	123	149	53	32	357	134	47	40	221	96	112	33	241	184	51	235	1054	156	4.5
L. S. 40-80.....	140	178	53	47	418	152	45	38	235	115	107	27	249	155	41	196	1098	200	5.8
L. S. 80-200.....	149	184	56	38	427	155	43	40	238	109	98	27	234	154	44	198	1097	199	5.8
L. S. Comp.....	131	180	52	42	405	85	39	33	157	82	96	27	205	147	45	192	959	61	1.8
Dol. 10-20.....	119	136	46	35	336	78	42	34	154	65	100	27	192	204	55	259	941	43	2.2
Dol. 20-40.....	137	144	51	44	376	81	46	37	164	92	99	27	218	178	49	227	985	87	4.5
Dol. 40-80.....	129	167	51	39	386	116	42	37	195	95	109	31	235	162	49	211	1027	129	6.6
Dol. 80-200.....	140	177	47	35	399	128	44	34	206	111	94	30	235	160	49	209	1049	151	7.8
Dol. Comp.....	128	150	52	37	367	116	48	43	207	95	102	28	225	152	48	200	999	101	5.2

* On basis of $\text{CaCO}_3 \approx$ content of limestone separates.

† On basis of $\text{CaCO}_3 \approx$ content of dolomite separates.

TABLE 2
Total calcium leached during 4 years from subsurface-zone additions of 2,000 pounds of CaO and equivalent dolomite separates
CaCO₃-equivalent per 2,000,000 pounds of moisture-free loam soil

TREATMENT	FIRST ANNUAL PERIOD			SECOND ANNUAL PERIOD			THIRD ANNUAL PERIOD			FOURTH ANNUAL PERIOD			TOTAL FOR 4-YEAR PERIOD			4-YEAR INCREASE IN OUTGO OVER CONTROLS		
	May to Sept.	June to Sept.	July to Sept.	May to Sept.	June to Sept.	July to Sept.	May to Sept.	June to Sept.	July to Sept.	May to Sept.	June to Sept.	July to Sept.	May to Dec.	Dec. to May	Total	Actual	On basis of additions per cent	
Control.....	128	136	53	40	357	108	43	37	188	69	81	27	177	126	50	176	898	...
Ca(OH) ₂	412	315	135	202	1064	210	113	115	438	133	121	60	314	188	77	265	2081	1183 59.2
L. S. 10-20.....	124	140	63	76	403	148	98	100	346	137	124	59	320	222	88	310	1379	481 14.0
L. S. 20-40.....	157	212	87	52	508	236	123	122	481	158	162	69	389	216	99	315	1693	795 23.1
L. S. 40-80.....	216	276	127	167	786	258	131	129	518	170	147	79	396	198	90	288	1988	1090 31.7*
L. S. 80-200.....	281	299	131	186	897	242	128	127	497	157	135	67	359	196	85	281	2034	1136 33.0
L. S. Comp.....	199	244	95	144	682	214	121	116	451	159	132	64	355	200	90	290	1778	880 25.6
Dol. 10-20.....	127	126	49	41	343	115	36	41	192	84	81	30	195	119	48	167	897	-1 7.2
Dol. 20-40.....	105	143	49	58	355	127	62	63	252	85	103	43	231	140	61	201	1039	141 15.1
Dol. 40-80.....	139	153	55	72	419	128	81	76	285	108	102	65	275	141	71	212	1191	293 20.7
Dol. 80-200.....	157	175	88	88	479	161	89	87	337	131	113	45	289	132	63	195	1390	402 13.2
Dol. Comp.....	145	153	54	80	432	139	72	69	280	101	100	44	245	138	59	197	1154	256

* On basis of CaCO₃ ≈ content of limestone separates.

† On basis of CaCO₃ ≈ content of dolomite separates.

‡ L. S. = Limestone.

§ Dol. = Dolomite.

TABLE 3
Total magnesium leached during 4 years from surface-zone additions of 2,000 pounds of CaO and equivalent limestone and dolomite separates
CaCO₃-equivalent per 2,000,000 pounds of moisture-free loam soil

TREATMENT	FIRST ANNUAL PERIOD			SECOND ANNUAL PERIOD			THIRD ANNUAL PERIOD			FOURTH ANNUAL PERIOD			TOTAL FOR 4-YEAR PERIOD			4-YEAR INCREASE IN OUTGO OVER CONTROLS			
	May 10 to Sept.	Sept. 10 to Dec.	Dec. 10 to March	May 10 to Sept.	Sept. 10 to Dec.	Dec. 10 to March	May 10 to Sept.	Sept. 10 to Dec.	Dec. 10 to March	May 10 to Sept.	Sept. 10 to Dec.	Dec. 10 to March	May 10 to Sept.	Sept. 10 to Dec.	Dec. 10 to March	Actual	On basis of O ₂ additions	Percent	
Controls	34	39	18	20	111	34	20	20	74	31	32	14	77	43	31	74	336	...	...
Ca(OH) ₂	59	52	19	22	152	38	21	21	80	24	26	15	65	43	24	67	364	28	...
L. S. 10-20	31	33	17	19	100	41	19	21	81	29	27	20	76	47	26	73	330	-6	...
L. S. 20-40	33	40	15	27	115	39	22	19	80	31	33	17	81	52	22	74	350	14	5.4
L. S. 40-80	39	46	16	16	117	46	20	17	83	36	31	15	82	46	19	65	347	11	4.2
L. S. 80-200	43	48	18	14	123	53	20	19	92	33	34	15	82	43	23	66	363	27	10.4
L. S. Comp.	34	46	17	19	116	30	19	19	68	26	28	18	72	45	25	70	326	-10	...
Dol. 10-20	31	36	17	14	98	30	20	23	73	23	37	15	75	59	26	85	331	-5	...
Dol. 20-40	35	35	16	16	102	39	21	19	79	28	38	16	82	58	33	91	354	18	1.0
Dol. 40-80	37	43	17	15	112	40	20	19	79	24	34	19	77	61	30	91	359	23	1.3
Dol. 80-200	36	47	17	14	114	44	20	18	82	36	36	19	91	69	36	105	392	56	3.2
Dol. Comp.	34	43	17	14	108	39	21	21	81	34	29	18	81	54	26	80	350	14	0.8

* On basis of MgO content, terms of CaCO₃ \approx , of limestone separates.

† On basis of MgO content, terms of CaCO₃ \approx , of dolomite separates.

EFFECT OF CALCIUM AND MAGNESIUM ON SOIL LEACHINGS: I

TABLE 4
Total magnesium leached during 4 years from subsurface-zone additions of 2,000 pounds of CaO and equivalent limestone and dolomite separates
CaCO₃-equivalent per 2,000,000 pounds of moisture-free loam soil

TREATMENT	FIRST ANNUAL PERIOD			SECOND ANNUAL PERIOD			THIRD ANNUAL PERIOD			FOURTH ANNUAL PERIOD			TOTAL FOR 4-YEAR PERIOD			4-YEAR INCREASE IN OUTGO OVER CONTROLS		
	May to Sept.	Sept. to Dec.	Dec. to Mar.	May to Sept.	Sept. to Dec.	Dec. to Mar.	May to Sept.	Sept. to Dec.	Dec. to Mar.	May to Sept.	Sept. to Dec.	Dec. to Mar.	May to Sept.	Sept. to Dec.	Dec. to Mar.	Actual	On basis of additions per cent	
Controls.....	34	39	18	20	111	34	20	20	74	31	32	14	77	43	31	74	336	...
Ca(OH) ₂	37	25	14	20	96	36	21	21	78	18	23	17	58	33	36	69	301	-35
L. S. 10-20.....	36	33	19	25	113	38	25	25	88	25	27	19	71	63	26	89	361	25
L. S. 20-40.....	42	41	20	18	121	43	25	26	94	26	28	16	70	42	31	73	358	22
L. S. 40-80.....	44	42	20	27	133	37	31	22	90	22	25	20	67	32	22	54	344	8
L. S. 80-200.....	47	39	18	26	130	40	24	21	85	23	24	18	65	32	21	53	333	-3
L. S. Comp.....	44	43	19	32	138	37	30	23	90	21	23	16	60	42	26	68	356	20
Dol. 10-20.....	39	42	20	19	120	57	28	28	113	53	53	27	133	82	42	124	490	154
Dol. 20-40.....	32	62	26	35	155	87	48	49	184	58	81	40	179	102	61	163	681	345
Dol. 40-80.....	47	89	40	50	226	95	65	60	220	77	79	56	212	128	62	190	848	512
Dol. 80-200.....	77	114	47	64	302	116	73	72	261	90	89	39	218	106	60	166	947	611
Dol. Comp.....	54	85	36	52	227	97	56	55	208	62	77	40	179	100	55	155	769	433

* On basis MgO content, terms of $\text{CaCO}_3 \approx$, of limestone separates.

† On basis MgO content, terms of $\text{CaCO}_3 \approx$, of dolomite separates.

TABLE 5
Total calcium-magnesium leached during 4 years from surface-zone additions of 2,000 pounds and equivalent limestone and dolomite separates
CaCO₃-equivalent per 2,000,000 pounds of moisture-free loam soil

TREATMENT	FIRST ANNUAL PERIOD			SECOND ANNUAL PERIOD			THIRD ANNUAL PERIOD			FOURTH ANNUAL PERIOD			4-YEAR INCREASE IN OUTGO OVER CONTROLS			
	May 10 to Sept. 10			May 10 to Sept. 10			May 10 to Sept. 10			May 10 to Sept. 10			May 10 to Sept. 10			
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	Actual	Qd additions of CaCO ₃	per cent	
Controls	162	175	71	60	468	142	63	57	262	100	113	41	254	169	81	...
Ca(OH) ₂	299	253	74	69	695	176	64	60	300	103	108	42	253	192	65	257
L. S. 10-20	164	160	66	57	447	157	59	56	272	108	134	50	292	216	85	301
L. S. 20-40	156	189	68	59	472	173	69	59	301	127	145	50	322	236	73	309
L. S. 40-80	179	224	69	63	535	198	65	55	318	151	138	42	331	201	60	261
L. S. 80-200	192	232	74	52	550	208	63	59	330	142	132	42	316	197	67	264
L. S. Comp.	165	226	69	61	521	115	58	52	225	108	124	45	277	192	70	262
Dol. 10-20	150	172	63	49	434	108	62	57	227	88	137	42	267	263	81	344
Dol. 20-40	172	179	67	60	478	120	67	56	243	120	137	43	300	236	82	318
Dol. 40-80	166	210	68	54	498	156	62	56	274	119	143	50	312	223	79	302
Dol. 80-200	176	224	64	49	513	172	64	52	288	147	130	49	326	229	85	314
Dol. Comp.	162	193	69	51	475	155	69	64	288	129	131	46	306	206	74	280

EFFECT OF CALCIUM AND MAGNESIUM ON SOIL LEACHINGS: I

TABLE 6
Total calcium-magnesium leached during 4 years from subsurface-zone additions of 2,000 pounds of CaO and equivalent limestone and dolomite separates
CaCO₃-equivalent per 2,000,000 pounds moisture-free loam soil

TREATMENT	FIRST ANNUAL PERIOD			SECOND ANNUAL PERIOD			THIRD ANNUAL PERIOD			FOURTH ANNUAL PERIOD			TOTAL FOR 4-YEAR PERIOD			4-YEAR INCREASE IN OUTGO OVER CONTROLS		On basis of additions per cent	
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	Actual	... . . . .	
Controls.....	162	175	71	60	468	142	63	57	262	100	113	41	254	169	81	250	1234	...	
Ca(OH) ₂ ,.....	449	340	149	222	1160	246	134	136	516	151	144	77	372	221	113	334	2382	1148	32.2
L. S. 10-20.....	160	173	82	101	516	186	123	125	434	162	151	78	391	285	114	399	1740	506	14.2
L. S. 20-40.....	199	253	107	70	629	279	148	148	575	184	190	85	459	258	130	388	2051	817	22.9
L. S. 40-80.....	260	318	147	194	919	295	162	151	608	192	172	99	463	230	112	342	2332	1098	30.8
L. S. 80-200.....	328	338	149	212	1027	282	152	148	582	180	159	85	424	228	106	334	2367	1133	31.7
L. S. Comp.....	243	287	114	176	820	251	151	139	541	180	155	80	415	242	116	358	2134	900	25.2
Dol. 10-20.....	166	168	69	60	463	172	64	69	305	137	134	57	328	201	90	291	1387	153	4.3
Dol. 20-40.....	137	205	75	93	510	214	110	112	436	143	184	83	410	242	122	364	1720	486	13.6
Dol. 40-80.....	186	242	95	122	645	223	146	136	505	185	181	121	487	269	133	402	2039	805	22.6
Dol. 80-200.....	234	289	135	152	781	277	162	159	598	221	202	84	507	238	123	361	2247	1013	28.4
Dol. Comp.....	199	238	90	132	659	236	128	124	488	163	177	84	424	238	114	352	1923	689	19.3

contribution (5). The calcium and magnesium contents of the rainfall have been determined over a period of years (2); but these are considered as being included in the outgo from the two controls, the results from which are averaged.

DISCUSSION

The findings are given in tables 1 to 6, in terms of CaCO_3 -equivalence per 2,000,000 pounds of moisture-free soil for each collection during each annual period and for the 4-year period. The averaged amount of calcium lost from the controls for the 4-year period was deducted from the outgo from each treated tank to give the increase attributable to the addition. Each amount so found is expressed both as pounds and as percentage of calcium content of the addition. The magnesium results are expressed in the same manner. The hydrated lime was so pure that its meagre content of magnesium could be disregarded. The precipitations for the four years, 1921-1925, were 52.52, 52.03, 46.99, and 39.25 inches, respectively.

Calcium outgo

Surface-zone additions.—The untreated soil was acid and devoid of carbonates, so that the total calcium outgo from the controls is considered as having been derived from the hydrolysis of the native calcium silicates and by the neutralization of biological end-products (table 1). Such neutralization might be effected either by bicarbonates evolved through hydrolysis, or by direct action of the biologically-induced acids upon the silicate complexes. The total CaCO_3 -equivalent outgo of 898 pounds from the controls for the 4-year period represents 10 per cent of the 0.4495 per cent CaCO_3 -equivalent of the total non-carbonate CaO content. From previous studies upon the same soil (1) it may be stated that the full increase in outgo from the $\text{Ca}(\text{OH})_2$ addition was derived from the hydrolysis of absorption complexes formed within a period of 10 days. Those absorption compounds were derived in part from the direct combination of acid-reacting materials and $\text{Ca}(\text{OH})_2$ and in part from their subsequent reaction with the CaCO_3 derived from that part of the hydrate addition which was not directly absorbed. A similar speedy fixation may be attributed to the finer limestone separates; but a previous contribution (5) has shown that considerable carbonate residues from the coarser separates were still present after 4 years. The increases in outgo in those instances are therefore considered as having been derived jointly from hydrolysis of absorption compounds and from solution of carbonate residuals.

The extent of disintegration of the limestone additions in the surface zone should be gauged by the previously reported carbonate study (5), rather than by the increased calcium content of the leachings. These are subject to the absorptive action of the unsaturated subsurface zone which tends to cause a uniform calcium outgo; therefore, in 11 of the 12 comparisons between

the first annual losses from the controls and those from $\text{Ca}(\text{OH})_2$ and limestone and dolomite groups the differences due to additions are all less than 55 pounds. The one exception is that of the hydrated lime treatment, which gave for the first year an increase of 186 pounds, or 76 per cent of the 243-pound total for the 4-year period.

The limestone and dolomite group average for the second year was 191 pounds less than that for the first year, and also less than the group averages of the third and fourth years. The total calcium losses from both controls and treatments for the initial year were about twice as large as those for either of the succeeding annual periods. Enhanced biological activities, as a result of the aeration incident to screening and mixing before placement, are thus reflected, irrespective of additions. This phase of the subject will be considered in a subsequent contribution.

But in spite of the equalizing action of the untreated subsurface zone the effects of form and fineness are registered in all of the 4-year totals and in many of the losses for the annual periods. The greatest increase in outgo through the full soil depth for the 4-year period was obtained from the hydrated lime, yet this increase of 243 pounds is only 6.8 per cent of the addition. For the limestone group the maximum increase in outgo was 200 pounds, or 5.8 per cent of the addition. This increase was obtained from both of the two finer separates, 40-80-mesh and 80-200-mesh. The actual outgo of calcium in each of the 4 dolomite separates was less than that from its corresponding limestone separate, but the results are magnified when expressed in percentage on the basis of the lesser occurrence of CaCO_3 in the dolomite.

Subsurface-zone additions.—The annual calcium outgo from each of the several subsurface-zone additions was greatest during the first year and, with the exception of that from the 10-20-mesh dolomite separate, every annual outgo gave a progressive decrease thereafter (table 2). In the absence of opportunity for absorption after movement of the free-soil water from the zone of treatment, direct determinations of the differences caused by variation in form and fineness of materials are recorded. All treatments show consistent increases in calcium outgo for annual and total periods, although the effect of the greater solubility of the hydrated lime and the influence of fineness upon solution and disintegration of both limestone and dolomite separates are more definitely shown. The greater availability of the hydrated lime, or its greater yield of total calcium salts, is especially marked during the first year. The increased outgo of 707 pounds during that year was equivalent to nearly 60 per cent of the outgo during the full 4-year period. Although the hydrate addition gave the maximum outgo for the first year, the 80-200-mesh limestone separate gave a greater outgo during each of the succeeding 3 years, so that the increases from hydrated lime and 80-200-mesh additions for the 4-year period were practically identical, namely, 33 per cent. To only a slightly less extent was the same true also for the increase

of 31.7 per cent from the 40-80-mesh limestone. The order of increase over the control-outgo was in accord with the increase in fineness of separates.

The calcium losses from the low-calcium dolomite group were uniformly less than those from the limestone group, but the influence of fineness upon

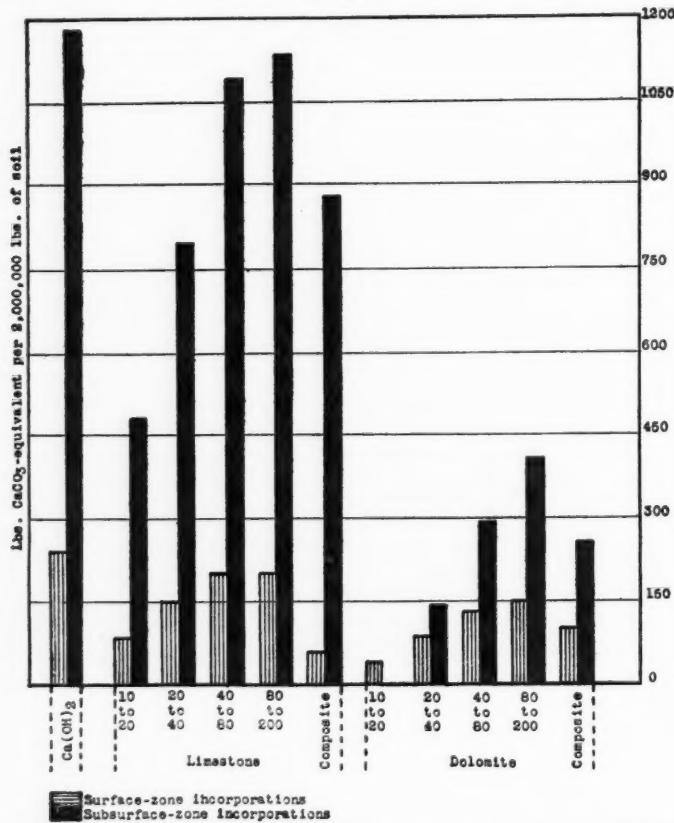


FIG. 1. TOTAL CALCIUM OUTGO IN EXCESS OF THAT FROM LOAM CONTROLS DURING 4 YEARS AS A RESULT OF 2000-POUND CaO-EQUIVALENT ADDITIONS OF Ca(OH)₂ AND LIMESTONE AND DOLOMITE SEPARATES OF 10-20-, 20-40-, 40-80- AND 80-200-MESH FINENESS—SURFACE-ZONE AND SUBSURFACE-ZONE INCORPORATIONS

Terms of CaCO₃-equivalence per 2,000,000 pounds of soil, moisture-free basis

outgo is especially marked. The annual recoveries from the 10-20-mesh separate were slightly less than those from the control for 2 years and slightly more for the other two annual periods, with a 4-year difference of only 1 pound. Though inactive for the first annual period, the 20-40-mesh separate

gave increases for the succeeding 3 years. The differences between the losses from the controls and those from the two finer separates were quite appreciable for each of the 4 annual periods. It will be remembered that the calcium losses from the dolomite series, with a maximum increase of 20.7 per cent for the finest subdivision, are calculated on the basis of the CaCO_3 content of the dolomite.

In comparing the increased losses from the subsurface-zone additions with corresponding losses from the surface-zone additions, it is evident that the

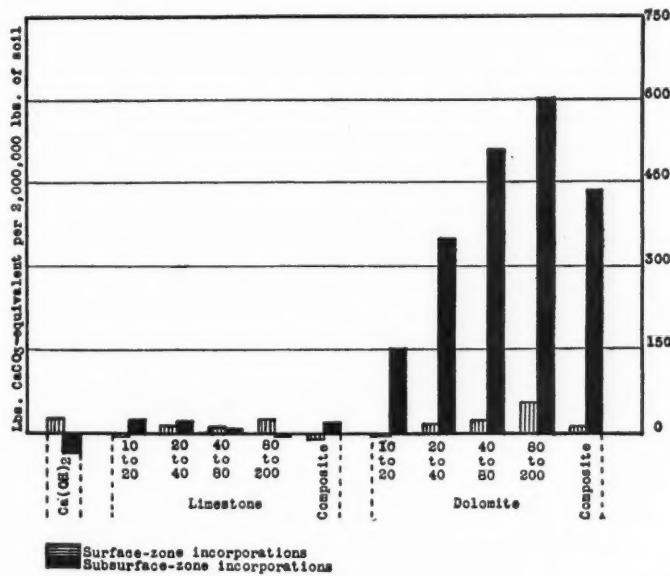


FIG. 2. TOTAL MAGNESIUM OUTGO IN VARIANCE FROM THAT OF LOAM CONTROLS DURING 4 YEARS AS A RESULT OF 2000-POUND CaO -EQUIVALENT ADDITIONS OF $\text{Ca}(\text{OH})_2$ AND LIMESTONE AND DOLOMITE SEPARATES OF 10-20-, 20-40-, 40-80- AND 80-200-MESH FINENESS—SURFACE-ZONE AND SUBSURFACE-ZONE INCORPORATIONS

Terms of CaCO_3 -equivalence per 2,000,000 pounds of soil, moisture-free basis

deeper incorporations yielded a higher calcium content to the leachings in every case. These differences were greatest, 26.3 per cent and 27.2 per cent, respectively, for the hydrated lime and for the 80-200-mesh limestone. Partial absorption from the calcium-impregnated leachings during their movement through the layer of untreated soil is one factor responsible for these consistent differences; but, in addition, previously reported results (5) upon carbonate residuals demonstrated that the disintegration of carbonate additions was more rapid and extensive in the lower zone. In the case of the

coarsest separate, the lower-zone incorporation gave a disintegration 8 times as great as that brought about by the same incorporation in the upper zone (5).

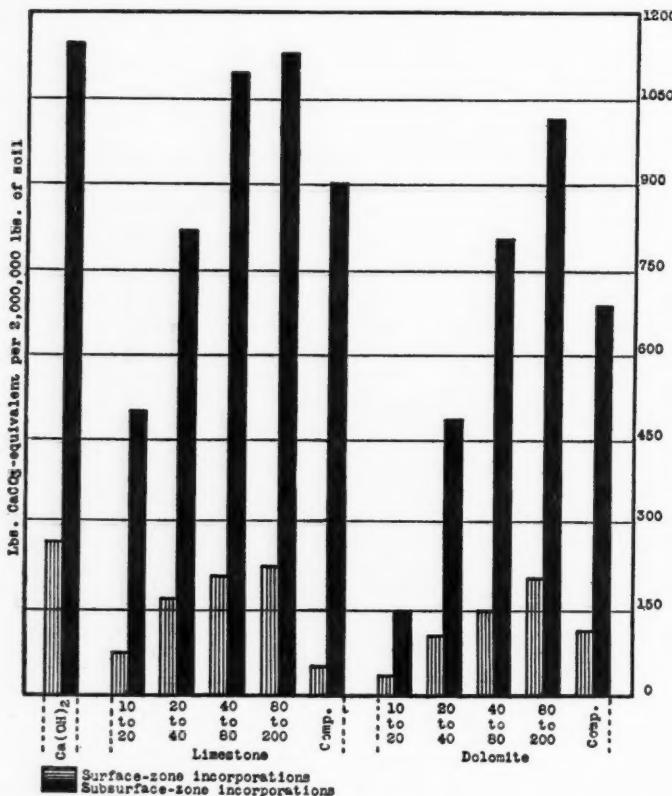


FIG. 3. TOTAL CALCIUM-MAGNESIUM OUTGO IN EXCESS OF THAT FROM LOAM CONTROLS DURING 4 YEARS AS A RESULT OF 2000-POUND CaO-EQUIVALENT ADDITIONS OF Ca(OH)₂ AND LIMESTONE AND DOLOMITE SEPARATES OF 10-20-, 20-40, 40-80- AND 80-200-MESH FINENESS—SURFACE-ZONE AND SUBSURFACE-ZONE INCORPORATIONS

Terms of CaCO₃-equivalence per 2,000,000 pounds of soil, moisture-free basis

Magnesium outgo

Surface-zone additions.—The 4-year magnesium outgo from the untreated carbonate-free acid control was equivalent to only 336 pounds of CaCO₃, as compared with a 898-pound CaCO₃-equivalence of calcium (table 3). Ultimate analyses of the soil used showed that the total CaO content of 0.2517 per cent was equivalent to 8990 pounds of CaCO₃, whereas the MgO con-

tent of 0.4116 per cent was equivalent to 20,440 pounds of CaCO_3 . From this it is seen that the native magnesium was very much more firmly fixed.

With the exception of the outgo from the hydrated lime treatment during the first year, there was no appreciable increase in magnesium outgo. Previously reported findings (4) from full-depth lime additions to the same soil showed a repression of magnesium outgo and the same finding appears for the subsurface-zone incorporations of table 4. It would seem, therefore, that the increased magnesium content from the hydrated lime during the initial year may be attributed to interchange exerted by surface-zone-derived neutral calcic salts during their passage through the untreated subsurface zone. The differences in magnesium outgo from the limestone series are small, varying from plus to minus, with only 3 small plus gains for 4-year totals, the maximum being only 10 per cent of the magnesium carbonate impurity of the limestone.

The annual and 4-year magnesium totals from the dolomite series are small, and the 4 plus totals represent but small fractions—a maximum of 3.2 per cent—of the magnesium content of the dolomite additions. The part of the added magnesium carbonate which was disintegrated was either held in the upper zone of treatment, or passing to the lower zone, it was there absorbed.

Subsurface-zone additions.—During 3 of the 4 years the hydrated lime caused a repression of magnesium outgo from the zone where calcium was in excess (table 4). This is in accord with our previous findings (4).

In the limestone group there were small increases in outgo for the 5 treatments during the first 2 years; but the reverse was true with one exception during the second 2 years. The four totals which gave plus quantities are all small and since they represent mere fractions of the magnesium carbonate content of the added limestone, which had fully disintegrated in two cases, it is evident that none of the native magnesium was forced into the leachings by interchange.

The annual amounts of magnesium coming from the slowly disintegrating 10-20-mesh dolomite separate were, in order, only 9, 39, 56, and 50 pounds. The other separates yielded larger quantities for annuals and totals in general accord with the order of fineness.

In comparing the magnesium increases derived from surface and subsurface additions, every annual and each total period shows a greater outgo from the subsurface-zone additions. The maximum difference of 31.2 per cent of the added MgCO_3 was obtained from the 80-200-mesh dolomite separate.

Total calcium-magnesium

Surface-zone additions.—The difference in zone of incorporation involves either the factor of basic interchange, or the reverse factor of "reciprocal repression" (3, 4). It is therefore necessary to consider the total calcium-magnesium outgo. This is done in tables 5 and 6 for the surface-zone and subsurface-zone incorporations, respectively. In these tables the full value of

3,570 pounds CaCO_3 -equivalence (2,000 pounds of CaO) of additions is used as the basis of calculation for both high-calcic and dolomitic materials.

The calcium-magnesium losses from controls and those from hydrated lime are practically identical for the third and fourth years; but the larger increase from the hydrated lime during the first year and the smaller for the second give an aggregate equivalent to 7.6 per cent of the addition.

In 10 of the high-calcic limestone additions to the tanks the magnesium impurity represents an appreciable aggregate, whereas in the 10 dolomite additions the calcium and magnesium carbonates are in near-equivalence. Neither annual nor total calcium-magnesium losses from the coarser high-calcic limestone differ greatly from those yielded by the controls; but, with increasing fineness, there is a definite increase in outgo. The orders of fineness and of increased outgo are parallel, but, as a result of the absorptive action of the untreated subsurface zone the maximum loss, that from the 80-200-mesh separate, is only 6.3 per cent of the addition. In slightly less degree, the same may be said of the corresponding dolomite separates.

Subsurface-zone additions.—The hydrated lime gave the greatest calcium-magnesium outgo of 1148 pounds, or 32.2 per cent of the addition (table 6). As a result of the minus quantity of magnesium, due to the repression of magnesium solubility and an outgo less than that from the controls, the total calcium-magnesium loss is less than the total outgo of calcium.

With the exception of the 10-20-mesh dolomite separate for the first year, all additions registered an appreciable increased annual outgo. The maximum calcium-magnesium outgo from the $\text{Ca}(\text{OH})_2$ addition was closely followed in order by limestone of 80-200-mesh and of 40-80-mesh and by dolomite of 80-200-mesh fineness with 1133 pounds, 1098 pounds, and 1013 pounds, respectively, or 31.7 per cent, 30.8 per cent, and 28.4 per cent. When thus incorporated, it would appear that, for the 4-year period, the hydrated lime, two finer limestone separates, and the finest dolomite separates may be considered of about equivalent values. As the two limestone separates increase in size, the disintegration, or greater solubility, of the high-calcic limestone is more pronouncedly shown.

In each of 54 of the 55 annual and total comparisons between increases from surface-zone and subsurface-zone incorporations, the latter shows the greater outgo.

Taken as a whole, under all conditions, the results from the composites may be said to conform most closely to the responses from the 20-40-mesh separates.

SUMMARY

Results are given from a 4-year study with a 34-unit lysimeter installation to determine the influence of form, soil-zone and fineness of lime and magnesia incorporations upon the outgo of calcium and magnesium from a constant equivalent of 2,000 pounds of CaO .

The maximum increase in calcium outgo from surface-zone incorporations

during 4 years was only 6.8 per cent of the addition and although some influence of form and fineness was recorded, the untreated subsurface zone tended to produce a uniform outgo.

In the absence of the retardative effect of a layer of untreated soil, the lower zone incorporations gave a maximum increased outgo of 33 per cent of the addition. Although the hydrated lime gave the greatest outgo during the first year—about 60 per cent of its total—its final increase was almost identical with the increases from the two finer limestone separates.

The losses from the high-calcic additions during the first year were uniformly maximum with decided decreases for the next three years for both zones. The differences due to fineness, zone, and time were not so great for the dolomite additions, but they showed positive effects from the imposed conditions.

There was a very little difference between the magnesia outgo from the controls and the losses from either limestone or dolomite additions to the surface zone. The losses from the subsurface-zone incorporations were consistently greater than those from the surface zone incorporations. Both zones generally gave the maximum annual outgo during the first year. The influence of fineness of dolomite separates was especially marked in the subsurface outgo for both annual and 4-year periods.

In the case of the completely disintegrated finer limestone separates in the subsurface zone, there was no increased magnesium outgo from the decomposition of the magnesium content of the limestone.

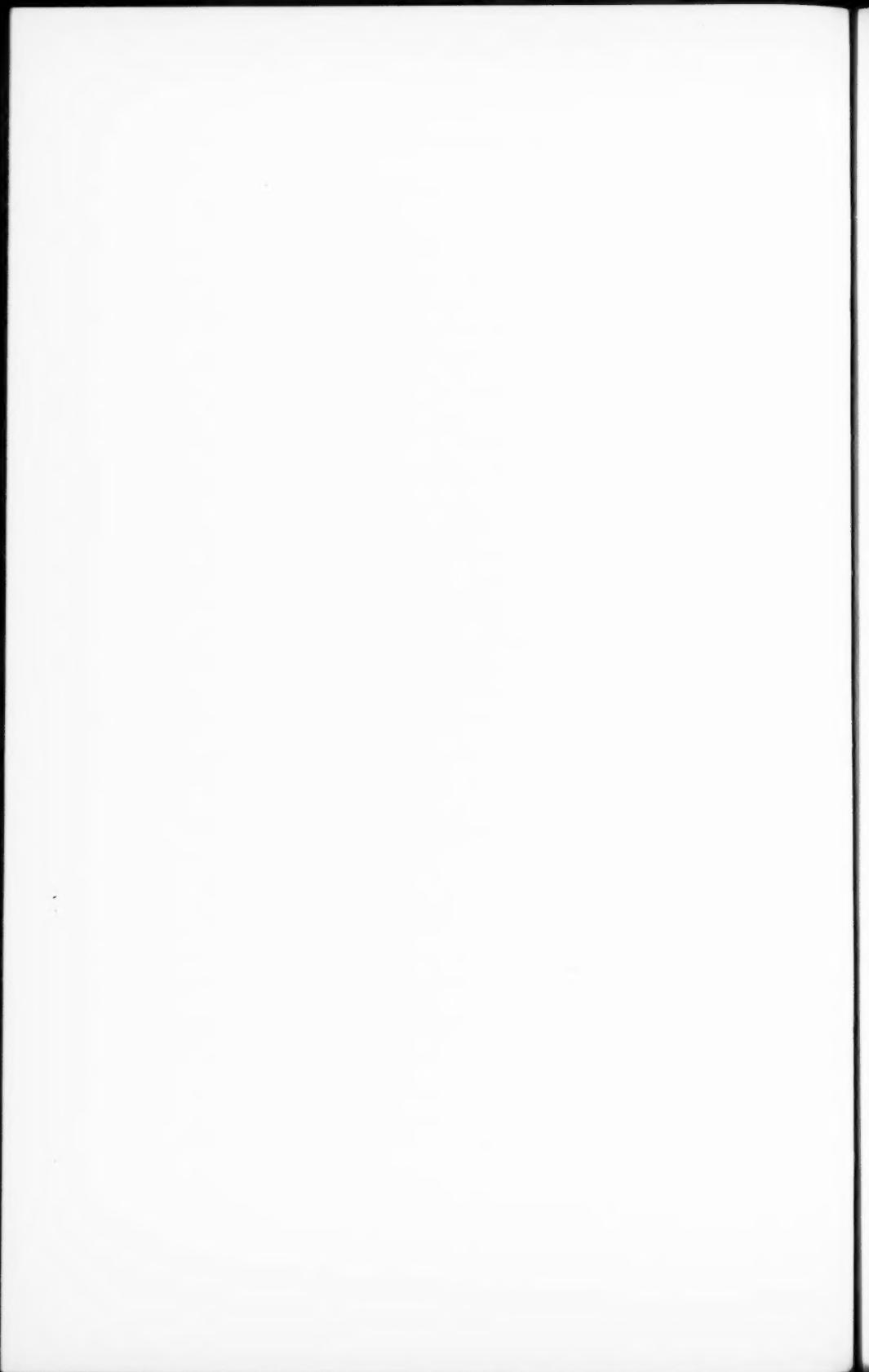
Repressed magnesia solubility was indicated by the high-calcic additions to the lower zone.

The total calcium-magnesium leachings from the surface-zone incorporations were small, comparable for limestone and dolomite, and related to the degree of fineness.

The total calcium-magnesia leachings from the subsurface-zone incorporations were uniformly greater than those from the surface-zone incorporations. Limestone separates gave totals uniformly higher than those from the corresponding dolomite separates, the disparity decreasing with increasing fineness. The total outgo from $\text{Ca}(\text{OH})_2$ and that from 100-mesh limestone and dolomite were almost identical.

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THE USE OF OAT STRAW IN A SYSTEM OF SOIL FERTILITY

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The results of many experiments (1, 2, 5, 10, 13, 14, 15, 17, 18, and 19) indicate that the addition of straw to a soil will decrease the growth and yield of the succeeding crop. There are, however, a few instances (3, 4, 5, and 12) where investigators have found that straw added to the soil has not caused a decrease in crop growth and that in some cases beneficial effects have been secured.

Sufficient evidence has been produced to prove that the detrimental effect of straw generally evidenced on the growth of the succeeding crop is due to a decrease in available nitrogen, which is utilized by the organisms involved in the decomposition of the straw, and, if nitrogen is the limiting factor in crop production, a decrease in growth results.

Several methods of overcoming this difficulty have been suggested, such as plowing the straw under in the early fall so that some decomposition will occur before the crop is planted the following season; adding sodium nitrate or ammonium sulfate in amounts large enough to furnish available nitrogen for the organisms which decompose the cellulose and carbohydrate material in the straw; or applying the straw to a legume crop before the latter is plowed under. The latter practice has been followed in the management of the crop residue plots at this station for several years.

EXPERIMENTAL

Since so much data have been published on the harmful effects of various kinds of straw, it seemed advisable to study the problem further and to determine under what conditions oat straw can be returned to the soil without interfering with the growth and yield of succeeding crops. The chief criticism of many of the experiments which have been conducted, is that the rates of application of the straw were much heavier than the amount of straw produced by an acre of grain. Considerable variation in yield of straw is secured on different soils and also from different kinds and varieties of grain grown on the same soil, consequently it is very difficult to select any definite amount of straw as representative of all conditions. The variation in yield of oat straw at this station is from $\frac{1}{2}$ to 1 ton per acre. Communications from several of the

¹ The authors wish to thank Dr. P. E. Brown for helpful suggestions received in connection with this study.

agricultural experiment stations in the corn belt give the following yields of straw from small grain; Indiana—oats $\frac{1}{2}$ to 1 ton, wheat and rye about $1\frac{1}{2}$ tons; Illinois—oats $\frac{1}{2}$ to $1\frac{1}{2}$ tons, wheat $2\frac{1}{2}$ tons; and Missouri—oats $2\frac{1}{2}$ tons, wheat $1\frac{3}{4}$ tons.

Since under most conditions some straw is utilized in farmyard manure, the rate of application of straw if it were returned to the soil on which it was grown, except under a strictly grain system of farming, would be less than the yield of straw per acre. In this experiment applications of oat straw at rates of $\frac{1}{2}$ and 1 ton per acre were used because these amounts, according to the data obtained, are not far from the average yield in this state and in adjoining states except Missouri.

Three different soil types were used in the investigation. All of these soils are of glacial origin, and the type name, reaction, total nitrogen, and organic carbon content of each soil are given in table 1.

TABLE 1
Total nitrogen and organic carbon content and the reaction of the soils used

SOIL TYPE	TOTAL N PER 2,000,000 POUNDS OF SOIL		REACTION
	pounds	pounds	
Webster silt loam.....	6,600	67,200	Basic
Clarion loam.....	2,800	.....	Neutral
Carrington loam.....	2,000	43,000	Medium acid

TABLE 2
Total nitrogen and carbon content of the oat straw, red clover, and Hubam clover used

MATERIAL	TOTAL NITROGEN		TOTAL CARBON
	per cent	per cent	
Oat straw.....	0.7	40.0	
Red clover.....	1.7	41.0	
Hubam clover.....	2.1	40.5	

GREENHOUSE STUDY

Four-gallon pots were filled with the Webster silt loam and Carrington loam and treated with oat straw cut into 1 inch lengths at the rates of $\frac{1}{2}$ and 1 ton per acre. Red clover, Hubam clover (annual white sweet clover), sodium nitrate, and ammonium sulfate were added to various pots in combination with the straw. The red clover and Hubam clover were applied at the rates of $\frac{1}{2}$ and 1 ton per acre with the straw and were mixed thoroughly with the soil. The sodium nitrate and ammonium sulfate were added to the dry straw before it was mixed with the soil so that these salts would be in immediate contact with the straw and would aid in its decomposition by furnishing available nitrogen for the microorganisms. The analyses of the organic materials added are given in table 2.

TABLE 3
Effect of the addition of oat straw, alone and in combination with red clover, Hubam clover, sodium nitrate, and ammonium sulfate, on the accumulation of nitrate in Carrington loam and in Webster silt loam

SOIL TYPE	TREATMENT	RATE PER ACRE				NITRATE CONTENT OF SOIL			
		Straw	Red clover	Hubam clover	$(\text{NH}_4)_2\text{SO}_4$	January 9	February 28	April 3	May 12
		tons	tons	tons	pounds	pounds	pounds	pounds	p.p.m.
Carrington loam	None					38	60	40	86
	Straw	1				36	65	38	70
	Straw		1			33	63	38	76
	Straw, red clover	1	1			31	62	34	76
	Straw, red clover	1	1	1		29	62	33	86
	Straw, NaNO_3	1	1		30.5	44	68	41	88
	Straw, NaNO_3	1	1	1	61.0	42	77	41	80
	Straw, $(\text{NH}_4)_2\text{SO}_4$	1	1		23.6	42	59	37	82
	Straw, $(\text{NH}_4)_2\text{SO}_4$	1	1	1	46.2	40	65	36	80
	Red clover					35	58	30	78
	Red clover					47	68	40	126
	Red clover					40	66	40	102
Webster silt loam	None					36	64	48	122
	Straw	1				36	63	40	110
	Straw		1			42	66	47	122
	Straw, red clover	1	1			52	76	44	117
	Straw, red clover	1	1	1		47	74	46	135
	Straw, Hubam clover	1			30.5	57	56	44	132
	Straw, Hubam clover	1	1		61.0	52	66	58	140
	Straw, NaNO_3	1	1		23.6	33	58	42	134
	Straw, $(\text{NH}_4)_2\text{SO}_4$	1	1	1	46.2	36	66	43	146
	Red clover					56	62	54	118
	Hubam clover					61	85	78	155

The first series of greenhouse pots were kept fallow and the nitrate content of the soils receiving the various treatments was determined about every six weeks after the experiment was started. The results of these analyses are given in table 3. It is evident from these data that the accumulation of nitrate has not been retarded to any great extent by the addition of straw to these soils.

In another experiment in which the straw was ground very fine, added to the Carrington loam, and incubated at 27°C. for different lengths of time, a considerable effect on the nitrate accumulation in the soil was produced. These data are given in table 4.

TABLE 4

Effect of finely ground oat straw applied at different rates and incubated for different lengths of time on the accumulation of nitrate in Carrington loam

TREATMENT	RATE PER ACRE	TIME OF INCUBATION AT 27°C.			
		2 weeks N as NO ₃	4 weeks N as NO ₃	6 weeks N as NO ₃	8 weeks N as NO ₃
None.....	tons	p.p.m.	p.p.m.	p.p.m.	p.p.m.
Straw.....	½	14	26	40	50
Straw.....	1½	8	18	44	50
Straw.....	5	3	13	28	40
Straw.....		0	2	7	20

TABLE 5

Effect of oat straw on the growth of wheat when applied to Webster silt loam, alone and in combination with red and Hubam clover

TREATMENT	RATE PER ACRE			TOTAL YIELD	
	Straw	Red clover	Hubam clover	Green weight	Dry weight
None.....	tons	tons	tons	gm.	gm.
Straw.....	1			174	74
Straw and red clover.....	1	½		153	63
Straw and Hubam clover.....	1		1	174	77
Red clover.....		½		192	81
Hubam clover.....			1	168	72
				162	68

The data given in table 4 agree with those of many other investigators. Since straw is not finely ground or chopped up into short lengths when applied in the field, however, such data are of little value except to indicate what takes place in the soil in immediate contact with the straw.

Another series of pots filled with Webster silt loam was treated at the same time as the series that was fallowed and planted to spring wheat. Throughout the growing period very little difference could be noticed among the various treatments. When the crop was harvested, it was evident that the straw alone had depressed the growth of the crop slightly. The results of this experiment are given in table 5.

FIELD STUDIES

Field investigations were conducted in connection with the greenhouse studies in the same soil types as are given in table 1. The effect of the addition

TABLE 6
Effect of the addition of straw to field plots, alone and in combination with alfalfa and Hubam clover

TREATMENT	SOIL TYPE	NITROGEN AS NITRATE		
		Nov. 12, 1924	April 10, 1925	May 4, 1925
		p.p.m.	p.p.m.	p.p.m.
Alfalfa.....	Carrington loam	8	16	62
Alfalfa, straw.....	Carrington loam	9	13	59
Hubam clover.....	Webster silt loam	7	21	58
Hubam clover, straw.....	Webster silt loam	3	21	45

TABLE 7
Effect of straw and straw mixed with Hubam clover on the accumulation of nitrate in soil in contact with the residue as compared with soil not in contact with the residue

SOURCE OF SOIL	N AS NO ₃	
	Webster silt loam	Clarion loam
Free from straw.....	99	12.7
Contact with straw.....	53	8.7
Contact with straw mixed with Hubam clover.....	113	19.4

TABLE 8
Effect of straw on the yield of corn when applied alone and in combination with red and Hubam clover

Rate of applications given in tons per acre

TREATMENT	MATERIALS APPLIED			YIELD OF CORN PER ACRE
	Straw	Red clover	Hubam clover	
None.....				bushels
Red clover.....		$\frac{3}{4}$		69.7
Hubam clover.....			$1\frac{1}{2}$	76.1
Oat straw.....	$\frac{3}{4}$			81.0
Red clover and oat straw.....	$\frac{3}{4}$	$\frac{3}{4}$		79.3
Hubam clover and oat straw.....	$\frac{3}{4}$		$1\frac{1}{2}$	76.1
None.....				78.9
				75.0

of straw in the fall, with and without legumes was studied in the first experiment. The results are given in table 6.

These soils were plowed in October. The alfalfa that was turned under

was the growth made after the third cutting, and was estimated at one-half ton per acre. The Hubam clover was the growth that occurred following winter wheat and was estimated at one and one-fourth tons per acre. Straw was applied at the rate of 1 ton per acre. The analyses were made on composite samples, each of which was composed of 10 samples taken from different portions of each plot. These samples represented the surface 6 inches of soil and since only a portion was in contact with the layer of straw between the furrows, this soil did not represent the effect of the straw on the soil immediately in contact with it. Consequently on May 21, 1925 another group of samples was taken from the plots which had grown wheat and Hubam clover in 1924, and had received an application of straw, which was plowed under in October. In many places it was possible to secure straw from the layer which was turned under and which was not mixed with Hubam clover. Other bunches of straw contained a large amount of Hubam clover. In every place where a sample was taken from the soil in contact with the residues another sample was taken from the same furrow at a distance of about two to three inches from the residues which were plowed under. The results of these analyses were averaged and are given in table 7.

The season was very dry and warm through April and May and much larger amounts of nitrate accumulated in field soils than is usually the case. There is no doubt, however, that the straw caused some reduction in nitrates in the soil that was in contact with it, but when Hubam clover was present, there was an increase in nitrates over the amount present in the soil that was not in contact with any residue.

In order to determine more accurately what effect the straw has on the growth of crops, 7 field plots located on Carrington loam at the Agronomy Farm were treated with straw, red clover, and Hubam clover, alone and in combination, and were planted to corn. The results of the first year are given in table 8.

The differences in the yield of corn in this experiment do not indicate that oat straw has caused any decrease in the yield. The results of the yields secured from other plots to which straw is applied with the second crop of red clover and plowed under in the fall also, do not show any harmful effects due to the treatment. These results, however, do not apply to soils which have a low content of available nitrogen; before any final statement can be made, therefore, further investigation is necessary on the effect on such soils of the plowing under of straw with the second crop of red clover.

SUMMARY

The effect of applications of oat straw on the accumulation of nitrate in soils when applied alone and in combination with red clover, Hubam clover, sodium nitrate, and ammonium sulfate was studied under greenhouse conditions. The addition of oat straw to a Webster silt loam and to a Carrington loam did not appreciably affect the accumulation of nitrates in these soils.

Wheat was also grown on one series of pots filled with Webster silt loam. Although no effect of the various treatments was noticeable in the development of the plants, the soil treated with oat straw alone yielded less than untreated soil.

A study of the nitrate accumulation in field soils to which oat straw had been applied and turned under with the second growth of red clover, Hubam clover, and alfalfa indicated that no retardation occurred except in that portion of the soil immediately in contact with straw which was not mixed with the legume.

The effect of additions of oat straw alone and in combination with red clover and Hubam clover to a Carrington loam had no retarding effect on the growth and yield of corn.

CONCLUSIONS

Without causing any injury to crop growth and yield, straw can be returned to many corn belt soils by spreading it on the second growth of red clover, on Hubam clover (annual white sweet clover), or on biennial sweet clover and by plowing in the fall wherever possible. The rate of application should not exceed one to one and one-half tons per acre.

The effect of large applications of straw on the growth of crops may be physical rather than biochemical since the straw reduces the nitrate content of only the soil in immediate contact with it.

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THE LOSS OF SOLUBLE SALTS IN RUNOFF WATER¹

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Many determinations of the salt content of streams and underground waters have been made, but little attempt has been made to determine the loss of various plant nutrient elements due to surface runoff. Some work concerning this matter has been done at the Missouri Experiment Station in connection with the soil erosion studies which have been in progress for the past eight years. A few determinations of the loss of nitrogen in the runoff water were given in an earlier report (2). This paper covers determinations made on the runoff water from the erosion plots having different cultural and crop treatments during the year May 1, 1924 to April 30, 1925. This must be considered as a progress report, since the samples are still being collected and further determinations will be made in the future. The year under consideration, however, is complete within itself. The rainfall during this time was somewhat above normal, being 45.2 inches whereas the average during the past eight years has been only 36.3 inches and that at Columbia during the past thirty-four years has been 37.6 inches.

Most of the attention in this work has been given to the loss of those elements which are considered of greatest importance from the standpoint of soil fertility.

PLAN OF THE WORK

Immediately after each rain, samples of the runoff water were drawn from each tank with a sampling tube, brought to the laboratory, and filtered through clay filters. Aliquots were taken and the samples stored for analysis. All the samples obtained during a 3-month period were composited in order to reduce the number of chemical determinations. For the most part the standard methods of water analysis as published by the American Public Health Association (1) were followed in this work. Other colorimetric methods were substituted for phosphorus.

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The treatments of the various plots in this experiment were as follows:

Soil erosion experiments. Plan of treatments

PLOT	CROP	SOIL TREATMENT
1	Soybeans since 1923 Rye as winter cover crop	Spaded 8 inches deep in spring and cultivated
2		Hoed in fall before seeding rye
3	No crop	Spaded 4 inches deep in spring and fallowed during season
4	No crop	Spaded 8 inches deep in spring and fallowed during season
5	Sod continually	Grass clipped and removed when necessary
5	Wheat annually	Spaded 8 inches deep in July and fallowed until October
6	Rotation—corn, wheat, clover*	Spaded 8 inches deep before corn, and hoed before wheat
7	Corn annually	Spaded 8 inches deep in spring. Corn cultivated

* During the year in which the results in this paper are reported this plot was in wheat followed by clover.

RESULTS

The analysis of the runoff from the various plots shows that the loss of soluble salts is a quantity worthy of consideration. The loss of plant-food materials is so large that it must be considered as one of the important means by which soils are depleted in certain of these elements. Table 1 shows that although the concentration is relatively low, the loss of mineral elements may make up a considerable proportion of the salt content found in our rivers. This fact becomes even more significant when we take into consideration the evaporation from stream water on its way to the sea.

The determinations made by McHargue and Peter (4) on water samples taken near the mouth of the Mississippi River show a decidedly greater concentration of calcium and magnesium than was present in the runoff from these plots, but the results with sulfur and potassium are not so widely different. The concentration of phosphorus is considerably higher in these samples than was reported by McHargue and Peter.

The results with calcium and sulfur on the sample from plot 4, May 1 to June 23, 1924 seemed too high, but because the amount of sample was limited, these determinations could not be repeated. The results of these two determinations, therefore, have not been included in table 2.

When the results are calculated to pounds per acre, the significance of the losses from a practical standpoint becomes more apparent. Table 2 shows the loss of the mineral elements as well as of the four forms of nitrogen. The loss of nitrogen by this means seems to be very slight. Some change in or even loss of nitrogen from these samples might be due to their long period of storage. However, tests made on fresh samples showed only traces of soluble nitrogen.

Most of the dissolved nitrogen was in organic form and the amount of nitrate nitrogen was surprisingly small. Of the mineral elements calcium and sulfur alone are lost in sufficient quantities to be of much practical importance, as may be seen from table 3. Attention might be called to the fact that the loss of calcium from wheat land has been 18.618 pounds per acre, an amount approximately three times that removed by the grain and straw of a 25-bushel wheat crop. The loss of calcium and sulfur from the uncropped fallow plots 2 and 3 is noticeably higher than from the other plots. The loss of potassium was highest from plot 4, whereas plot 1 showed the greatest loss of phosphorus. The loss of potassium in the runoff water from plots 2, 3, and 4 was greater than the amount ordinarily supplied by average applications of commercial fertilizer.

A comparison of tables 3 and 4 shows that the plant-food material lost in the form of soluble salts was small as compared with that lost in the solid material eroded from the plots that were cultivated a good portion of the year. On the other hand, the loss of plant-food material from sod land has been considerably greater in the form of soluble salts than in the eroded material.

Although tables 3 and 4 do not cover the same years, it is believed that the losses reported in table 4 are reasonably representative of the average for the duration of the experiment.

TOTAL SOLIDS

The total amount of soluble salts lost in the runoff water from these plots has been remarkably high for certain plots. Table 5 shows the loss of soluble salts per acre in comparison with the solid material eroded from the plots during the same period of time. It will be seen that in all the cultivated plots the solid material eroded is much the greater source of total material loss, but in the case of the plot in bluegrass, the weight of salts lost is 59.76 per cent of the weight of solid particles removed. From plot 6, which was in wheat followed by clover, the total loss of soluble salts was 6.96 per cent of the weight of sedimentary material removed. When the ignited salts are considered, approximately the same relation holds for the various plots. The relatively high loss of salts from plots 4 and 6 may be partly explained on the basis of results shown by LeClerc and Breazeale (3) who found that there may be a large amount of salts exuded from the surface of plant leaves and that these salts are washed off by rains. Plots 4 and 6 were covered with vegetation during the entire year whereas the mature crops of soybeans, of wheat, and of corn were removed from plots 1, 5, and 7 respectively. Plots 1 and 5 were then seeded to fall grains but the loss of salts from young plants is probably small as compared with older ones. The grass on plot 4 is usually cut with a lawn mower and allowed to fall back on the plot. There is doubtless a large loss of salts from this material.

The percentage of the weight of soluble salts lost on ignition is greater in the case of plots 1, 4, 5, and 6 which are kept in crops most of the time. The

TABLE I
Concentration of the various elements in the runoff water from different plots

PLOT	TREATMENT	DATES OF SAMPLING	RUN-OFF	N as NH ₃	N as NO ₃	C ₆ H ₅ CO ₂	Mg	K	Na	S	P	TOTAL SOLIDS 103°C.	TOTAL SOLIDS IGNITED	
			cu. ft.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	
1	Soybeans	May 1 to June 23, 1924	161.28	0.083	0.833	N.S.*	5.60	0.29	0.45	0.51	2.82	0.12	28.0	
		June 24 to July 31, 1924	116.38	0.042	0.500	Absent	3.81	0.13	0.45	0.79	3.53	0.25	50.0	
		August 1 to October 31, February 1 to April 30, 1925	330.05	0.042	1.083	Absent	5.00	0.09	0.61	0.94	4.00	1.50	85.0	
		November 1, 1924 to January 31, 1925	19.86	0.125	0.750	0.001	Trace	3.94	0.42	6.76	0.38	5.54	0.63	67.5
2	Spaded 4 inches	May 1 to June 23, 1924	167.85	Absent	0.833	N.S.	6.51	0.32	1.74	1.15	8.63	0.50	142.5	
		June 24 to July 31, 1924	128.39	Absent	0.667	Absent	0.08	4.75	0.35	4.15	0.77	4.51	0.30	70.0
		August 1 to October 31, February 1 to April 30, 1925	425.30	Absent	0.413	0.004	0.08	8.20	1.00	1.66	1.99	7.58	0.25	100.0
		November 1, 1924, to Janu- ary 31, 1925	11.29	N.S.	N.S.	Absent	N.S.	3.81	0.20	1.83	1.95	5.03	0.25	61.0
3	Spaded 8 inches	May 1 to June 23, 1924	157.70	0.125	0.500	N.S.	N.S.	6.30	Trace	0.61	0.25	4.09	0.38	136.0
		June 24 to July 31, 1924	124.42	Absent	0.413	Absent	0.08	4.20	0.02	1.55	1.71	4.52	0.38	56.5
		August 1 to October 31, 1924	170.64	0.83	0.750	0.001	Trace	6.09	0.20	3.62	1.05	6.58	0.25	65.5
		November 1, 1924, to Janu- ary 31, 1925	11.56	N.S.	N.S.	Absent	N.S.	5.33	0.35	0.35	0.40	6.17	5.00	115.0
		February 1 to April 30, 1924	268.04	Absent	0.583	Absent	N.S.	7.56	0.76	0.72	1.19	7.73	0.50	78.0

4	Sod	May 1 to June 23, 1924	81.94	Absent	0.833	N.S.	33.57	Trace	4.44	2.38	30.07	0.30	143.5	52.0	
		June 24 to July 31, 1924	64.69	Absent	0.083	N.S.	4.93	Trace	1.37	2.35	2.34	0.30	66.0	34.0	
		August 1 to October 31, 1924	110.23	N.S.	N.S.	Absent	N.S.	3.14	0.24	6.89	1.42	3.94	0.45	83.5	50.5
		November 1, 1924, to April 30, 1925	249.54	N.S.	N.S.	N.S.	6.55	0.07	2.43	1.04	5.33	0.30	85.0	43.0	
5	Wheat	May 1 to June 23, 1924	150.42	0.042	0.750	N.S.	5.94	0.09	1.12	0.59	3.64	0.50	114.0	39.5	
		June 24 to July 31, 1924	119.18	Absent	0.083	Absent	0.06	4.02	Trace	0.18	0.12	3.82	0.25	53.0	29.0
		August 1 to October 31, 1924	140.86	N.S.	N.S.	Absent	0.08	3.77	0.04	0.82	1.61	3.71	0.45	61.0	31.5
		November 1, 1924, to April 30, 1925	260.36	0.025	0.583	0.007	0.16	7.01	1.55	Trace	0.19	6.57	0.30	90.0	49.0
6	Wheat and clover	May 1 to June 23, 1924	89.54	0.025	0.250	N.S.	N.S.	4.88	Trace	0.70	0.26	3.34	0.45	136.5	64.0
		June 24 to July 31, 1924	93.78	Absent	0.083	N.S.	N.S.	3.06	0.07	1.08	0.75	2.13	0.12	40.5	22.0
		August 1, 1924, to April 30, 1925	211.18	0.500	0.583	Absent	0.14	12.03	0.23	0.41	0.13	6.82	0.12	82.32	41.47
		May 1 to June 23, 1924	151.29	Absent	0.750	N.S.	N.S.	6.91	0.31	0.74	0.54	4.07	0.30	109.0	45.5
7	Corn	June 24 to July 31, 1924	111.59	Absent	0.413	Absent	0.14	3.52	0.28	0.21	0.27	3.19	0.25	47.5	29.0
		August 1 to October 31, 1924	177.06	N.S.	0.10	0.14	2.13	1.81	0.89	1.19	7.62	0.12	53.08	39.23	
		November 1, 1924, to April 30, 1925	243.75	Absent	0.413	0.025	0.10	7.23	0.02	0.13	Trace	3.38	0.12	90.0	49.0

* N.S. = no sample.

TABLE 2
Chemical analysis of runoff water—erosion experiment—May 1, 1924, to April 30, 1925
Pounds of elements lost per acre

4	May 1 to June 23, 1924 June 24 to July 31, 1924 August 1 to October 31, 1924 November 1, 1924, to January 31, 1925	Absent 0.341 Absent 0.027 N.S. N.S. N.S. N.S.	N.S. N.S. N.S. N.S. N.S. N.S.	Trace 1.817 Trace 0.443 0.132 3.793 0.087 3.028	0.974 0.759 0.782 2.169	N.S. 0.123 0.756 0.097 0.248 45.962 0.374 105.919	58.717 21.320 10.983 27.797 53.582
	Total	0.368	11.483	0.219	9.081	3.811	9.567
5	May 1 to June 23, 1924 June 23 to July 31, 1924 August 1 to October 31, 1924 November 1, 1924 to April 30, 1925	Absent 0.032 Absent 0.499 N.S. N.S. 0.033 0.759	N.S. N.S. Absent 0.036 Absent 0.056 0.009 0.208	4.452 2.392 2.652 9.122	0.068 0.841 0.028 2.017	0.443 Trace 0.107 0.577 Trace 0.247	2.734 0.376 1.132 8.550
	Total	0.065	1.371	0.009	0.300	18.618	2.113
6	May 1 to June 23, 1924 June 24 to July 31, 1924 August 1, 1924 to April 30, 1925	0.011 0.011 Absent 0.039 0.527 0.615	N.S. N.S. N.S. N.S. Absent 0.148	2.182 0.433 12.686	0.313 0.033 0.432	0.116 0.506 0.432	1.493 0.351 7.192
	Total	0.538	0.665	0.148	16.301	0.276	1.251
7	May 1 to June 23, 1924 June 24 to July 31, 1924 August 1 to October 31, 1924 November 1, 1924 to April 30, 1925	Absent 0.567 Absent 0.230 N.S. N.S. Absent 0.503	N.S. N.S. Absent 0.078 0.009 0.123 0.030 0.122	5.220 1.961 1.875 8.800	0.234 0.156 1.594 0.024	0.559 0.117 0.784 0.158	0.408 0.150 1.048 Trace 4.114
	Total	1.300	0.039	0.323	17.856	2.008	1.618

* N.S. = no sample.

TABLE 3
Summary of the annual loss of various chemical elements in runoff water from the different treatments
 Pounds per acre

PLOT	TREATMENT	N AS NH ₃	N AS ORGANIC	N AS NO ₂	N AS NO ₃	Ca	Mg	K	Na	S	P
1	Soybeans	0.172	2.821	0.0001	0.132	15.356	0.500	2.299	2.457	11.465	2.776
2	Spaded 4 inches		2.003	0.008	0.221	26.132	2.626	7.747	5.794	26.506	1.156
3	Spaded 8 inches	0.168	2.070	0.001	0.050	23.186	1.219	5.512	3.770	22.338	1.447
4	Sod		0.368			11.483	0.2199	0.081	3.811	9.567	0.842
5	Wheat	0.065	1.371	0.009	0.300	18.618	2.113	1.525	1.892	16.167	1.232
6	Wheat followed by clover	0.538	0.665		0.148	16.301	0.2761	1.251	0.604	9.682	0.384
7	Corn		1.300	0.039	0.323	17.856	2.008	1.618	1.606	15.676	0.618

TABLE 4
Annual loss of plant-food elements in the eroded soil from the various treatments
 September 1, 1920, to August 31, 1922 (2, p. 38-40)

PLOT	TREATMENT	N	P	Ca*	S*
1	Not cultivated†	98.8	47.40	379.3	100.8
2	Spaded 4 inches fallowed	95.4	45.40	337.8	69.6
3	Spaded 8 inches fallowed	73.8	33.20	225.6	63.6
4	Sod	0.5	0.09	0.6	
5	Wheat annually	29.5	10.80	75.9	19.3
6	Corn, wheat, and clover	5.9	2.20	41.4	6.9
7	Corn annually	40.3	8.10	103.3	25.3

* One year's results.

† During the first 6 years of these experiments, plot 1 was uncultivated and uncropped. The land was kept bare by pulling the weeds.

TABLE 5
Loss of total soluble salts from plots with different treatments
 Pounds per acre

PLOT	TREATMENT	SOIL ERODED MAY 1, 1924 TO APRIL 30, 1925	TOTAL SOLUBLE SALTS, 103°C.	SOLID MATE- RIAL	TOTAL SALTS AFTER IGNITION	LOSS IN WEIGHT OF SALT BY IG- NITION	
						per cent	per cent
1	Soybeans	37190	249.9	0.67	101.7	0.27	59.3
2	Spaded 4 inches. Fallowed	89297	380.1	0.42	217.6	0.24	42.7
3	Spaded 8 inches. Fallowed	93728	309.1	0.33	169.7	0.18	45.1
4	Sod	388	231.9	59.76	113.6	29.28	51.0
5	Wheat	47694	277.2	0.58	132.8	0.28	52.1
6	Wheat and clover	2396	166.8	6.96	82.6	3.45	50.5
7	Corn	40326	265.1	0.66	144.7	0.36	45.4

salts coming from plots 2 and 3, which are fallow, or from plot 7, which is cultivated and has no winter cover crop, contain a larger percentage of inorganic salts than those carrying a crop the greater part of the year. The loss on ignition from plot 1, having soybeans followed by rye, is somewhat higher than that from the sod plots. No satisfactory reason has been found for this difference, since it would seem that it should fall intermediate between the corn land and the sod land.

SUMMARY

1. The runoff water from the soil erosion plots at the Missouri Experiment Station was sampled after each rain during the year May 1, 1924 to April 30, 1925. This water was passed through clay filters and the amount and composition of the soluble salts were determined on aliquot samples.
2. The total amount of dry salts lost varied from 166.8 pounds from the plot in wheat and clover to 380.1 pounds per acre from the plot which was spaded 4 inches deep in the spring and fallowed throughout the season.
3. Calcium and sulfur were lost in larger amounts than any of the other elements determined. The loss of potassium was relatively small but from several of the plots it amounted to considerably more than would ordinarily be applied in commercial fertilizer. The losses of magnesium, sodium, and phosphorus are too small to be of much practical importance.
4. The nitrogen determinations were incomplete on some of the samples, but these results as well as others reported earlier indicate that the surface runoff water is not a great source of nitrogen loss.
5. The soluble salts from the fallow plots showed a higher percentage of inorganic material, as indicated by a smaller loss on ignition, than did the soluble material coming from land carrying a crop.

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